

# Internal Review

*eRHIC*  
*CeC*

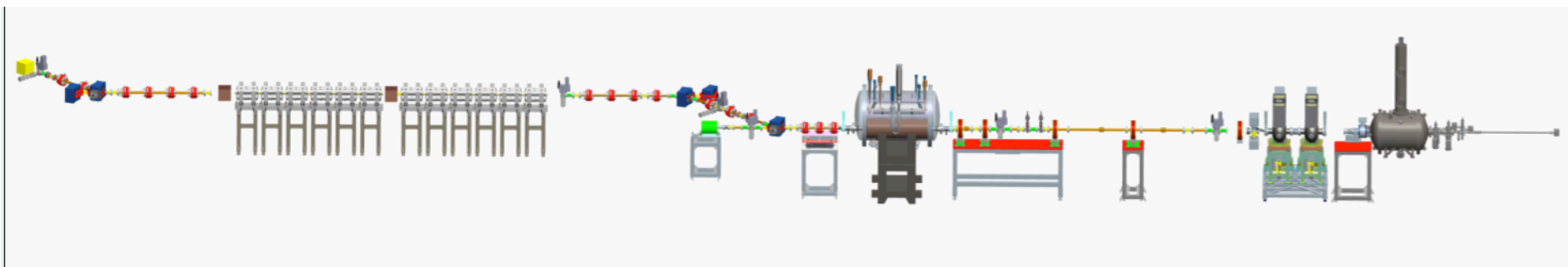
August 10, 2015

# *Coherent electron Cooling Proof of Principles Experiment*

*Vladimir N. Litvinenko - PI  
Igor Pinayev - Project physicist  
Joseph Tuozzolo - Project Engineer*

*for CeC team*

*C-AD, Brookhaven National Laboratory, Upton, NY, USA  
Stony Brook University, Stony Brook, NY, USA  
Niowave Inc., Lansing, MI, USA, Tech X, Boulder, CO, USA  
Budker Institute of Nuclear Physics, Novosibirsk, Russia  
STFC, Daresbury Lab, Daresbury, Warrington, Cheshire, UK*

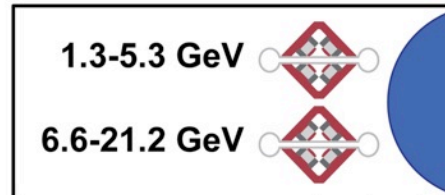


*Supported by BNL (LDRDs & PD), C-AD AR&DD, and NP DoE office Accelerator R&D grant*

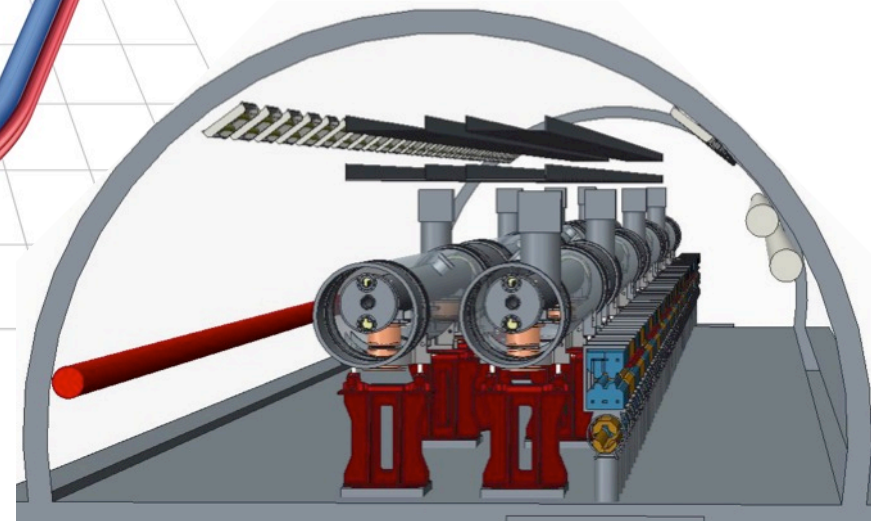
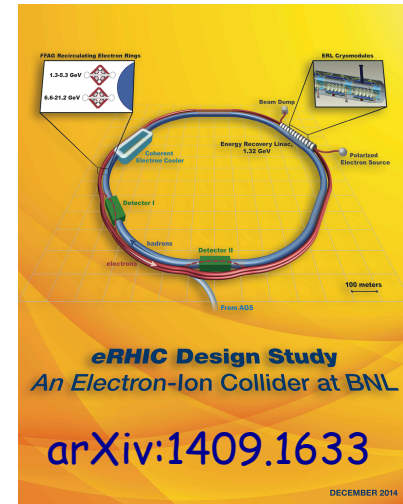
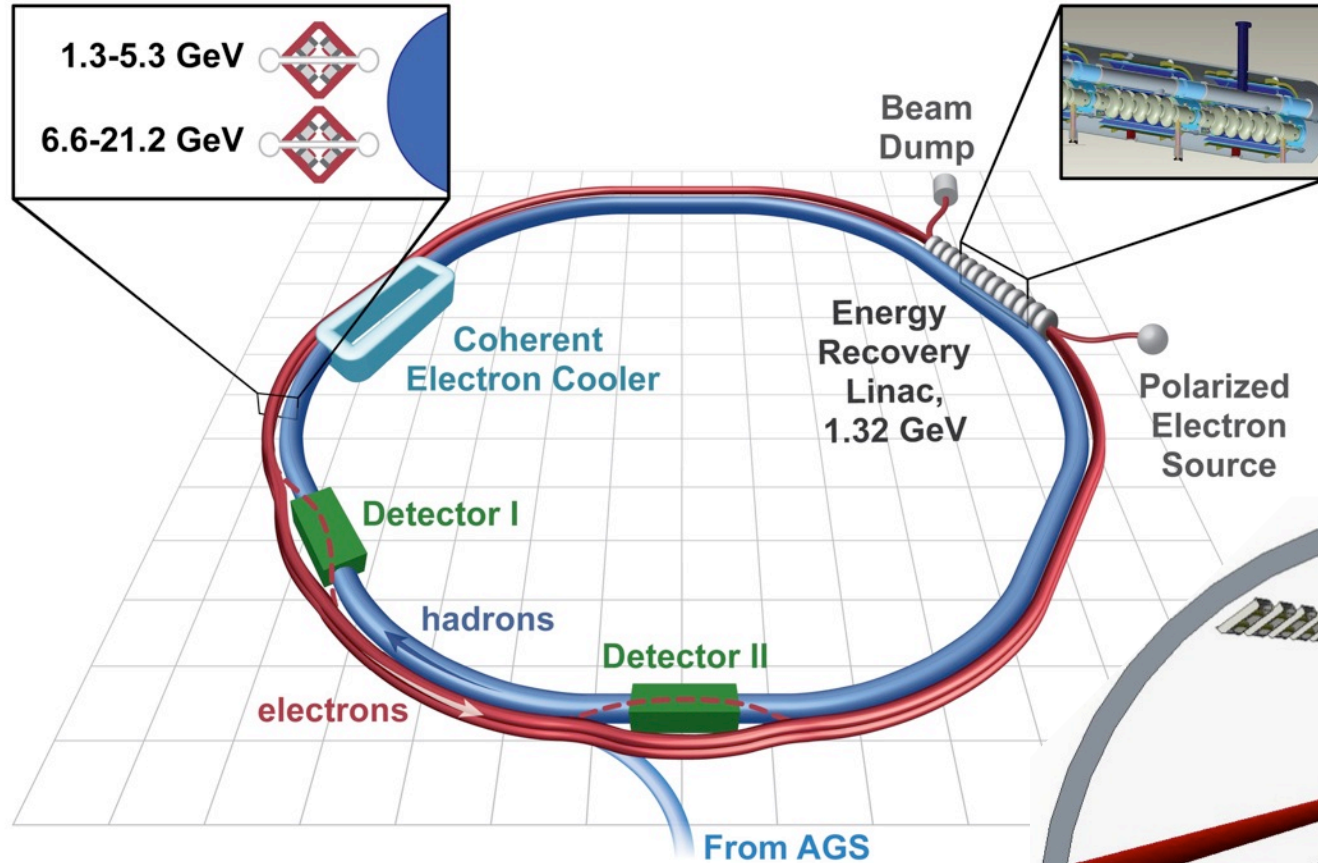
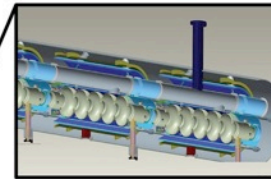
# eRHIC design

Highly advanced and energy efficient accelerator

## FFAG Recirculating Electron Rings

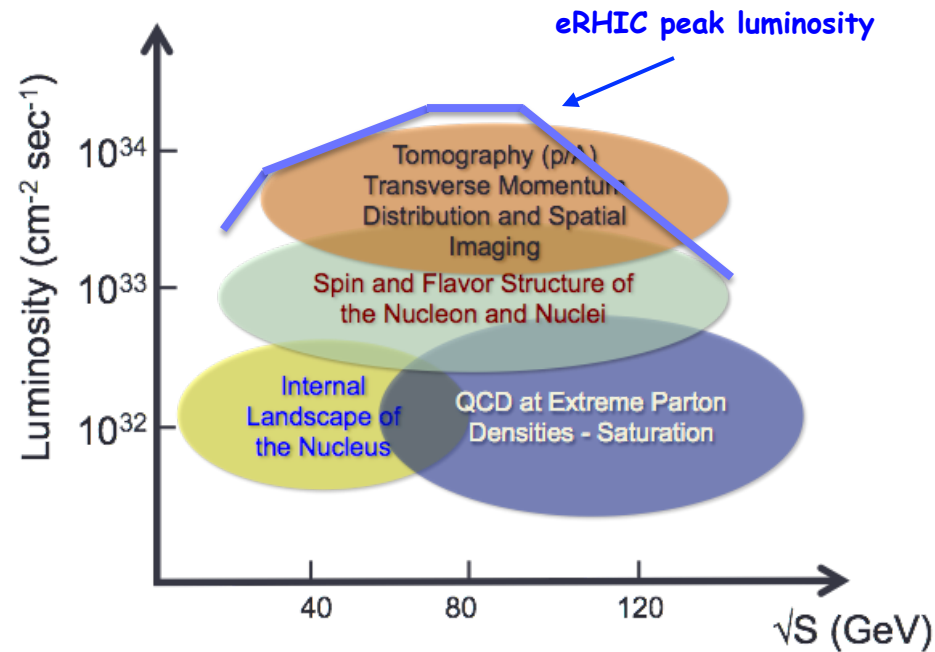
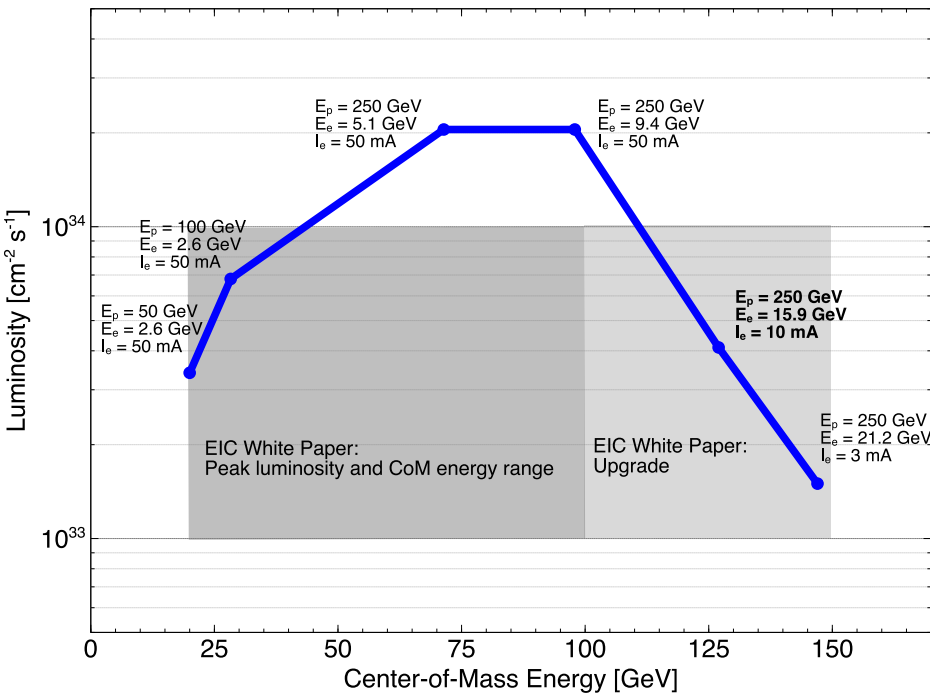


## ERL Cryomodules



$$4.1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1} \text{ for } \sqrt{s} = 126 \text{ GeV (15.9 GeV } e \uparrow \text{ on 250 GeV } p \uparrow \text{)}$$

# eRHIC peak luminosity vs. CoM energy



eRHIC design covers whole Center-of-Mass energy range, including "EIC White Paper Upgrade" region

Small beam emittances and IR design allows for full acceptance detector at full luminosity

# eRHIC hadron beam is 1,000 x brighter than current RHIC beams

	e	p	$^2\text{He}^3$	$^{79}\text{Au}^{197}$
Energy, GeV	15.9	250	167	100
CM energy, GeV		126	103	80
Bunch frequency, MHz	9.4	9.4	9.4	9.4
Bunch intensity (nucleons), $10^{11}$	0.07	3.0	3.0	3.0
Bunch charge, nC	1.1	48	32	19.6
Beam current, mA	10	415	275	165
Hadron rms normalized emittance, $10^{-6}$ m		0.2	0.2	0.2
Electron rms normalized emittance, $10^{-6}$ m		23	35	58
$\beta^*$ , cm (both planes)	5	5	5	5
Hadron beam-beam parameter		0.004	0.003	0.008
Electron beam disruption		36	16	6
Space charge parameter		0.08	0.08	0.08
rms bunch length, cm	0.4	5	5	5
Polarization, %	80	70	70	none
Peak luminosity, $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$		4.1	2.8	1.7

Very strong cooling is required

# Requirement vs. current cooling techniques

IBS growth time for eRHIC beam is about 20 seconds (for 250 GeV protons) and have to be contra-acted by cooling

RHIC's stochastic cooling can cool  $10^9$  ions in 5 nsec bucket with cooling time  $\sim$  1 hour. It is equivalent to cooling time for eRHIC 0.3 nsec bunches:

- Heavy ions  $>$  10 hours
- Protons  $>$  100 hours

Our best design for electron cooling promised to cool ion beam at 100 GeV with cooling time of one hour. Extending this \$150M facility to cool 250 GeV protons will provide cooling time of about 30 hours. It would be better than stochastic cooling, but definitely insufficient for eRHIC

**We need a better cooling mechanism.**

# "Classical: Coherent electron Cooling scheme

At a half of plasma oscillation

$$q_{\lambda_{FEL}} \approx \int_0^{\lambda_{FEL}} \rho(z) \cos(k_{FEL} z) dz$$

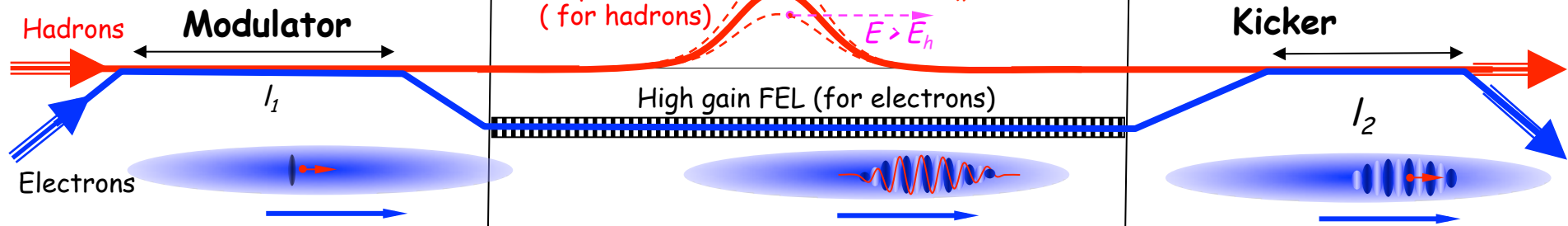
$$\rho_k = k q(\varphi_1); n_k = \frac{\rho_k}{2\pi\beta\epsilon_{\perp}}$$

Dispersion

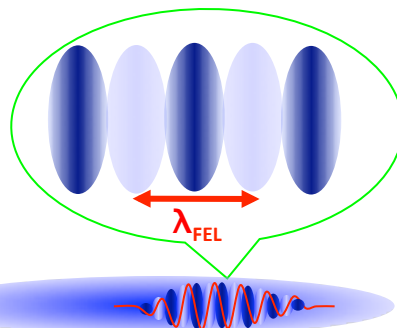
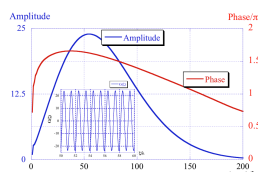
$$c\Delta t = -D_{zh} \cdot \frac{\gamma - \gamma_o}{\gamma_o}; D_{free} = \frac{L}{\gamma^2}; D_{chicane} = l_{chicane} \cdot \theta^2 \dots\dots$$

$$\Delta E_h = -e \cdot \mathbf{E}_o \cdot \mathbf{l}_2 \cdot \sin\left(k_{FEL} D \frac{E - E_o}{E_o}\right)$$

$$\left(\frac{\sin\varphi_2}{\varphi_2}\right) \cdot \left(\frac{\sin\varphi_1}{2}\right)^2 \cdot Z \cdot X; \mathbf{E}_o = 2G_o e \gamma_o / \beta \epsilon_{\perp n}$$



Amplifier of the e-beam modulation in an FEL with gain  $G_{FEL} \sim 10^2$

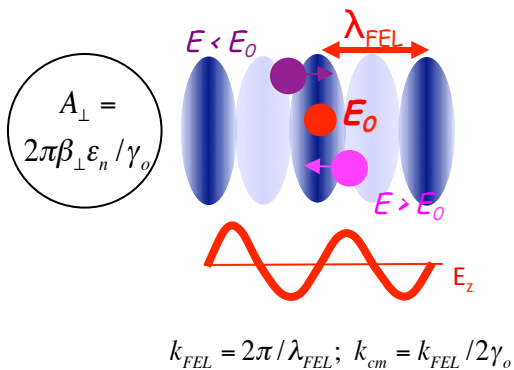


$$\lambda_{fel} = \lambda_w (1 + \langle \vec{a}_w^2 \rangle) / 2\gamma_o^2$$

$$\vec{a}_w = e \vec{A}_w / mc^2$$

$$L_G = L_{Go} (1 + \Lambda)$$

$$G_{FEL} = e^{L_{FEL} / L_G}$$



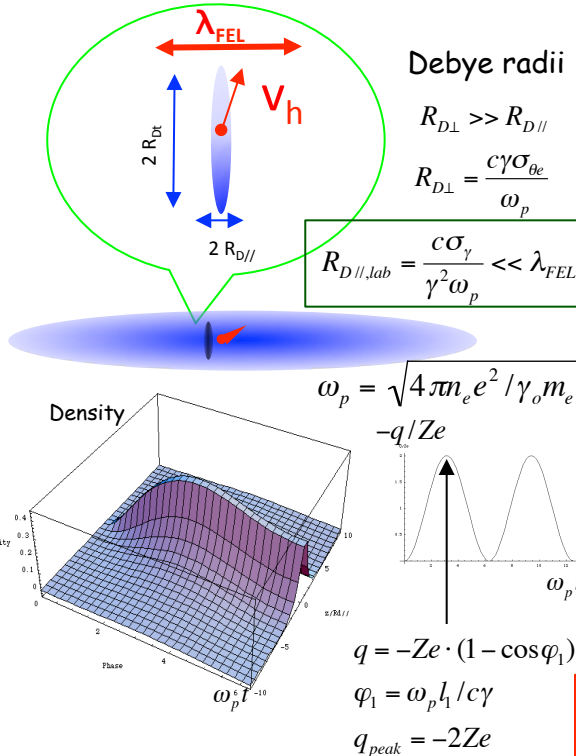
$$n_{amp} = G_o \cdot n_k \cos(k_{cm} z)$$

$$\Delta\varphi = 4\pi en \Rightarrow \varphi = -\varphi_0 \cdot \cos(k_{cm} z)$$

$$\vec{E} = -\vec{\nabla}\varphi = -\hat{z} \mathbf{E}_o \cdot X \sin(k_{cm} z)$$

$$\mathbf{E}_o = 2G_o \gamma_o \frac{e}{\beta \epsilon_{\perp n}}$$

$$X = q/e \cong Z(1 - \cos\varphi_1)$$



PRL 102, 114801 (2009)

PHYSICAL REVIEW LETTERS

week ending  
20 MARCH 2009

Coherent Electron Cooling

Vladimir N. Litvinenko<sup>1,\*</sup> and Yaroslav S. Derbenev<sup>2</sup>



# CeC limits

Each charged particle causes generation of an electric field wave-packet proportional to its charge and synchronized with its initial position in the bunch

$$\mathbf{E}_{total}(\xi) = E_o \cdot \text{Im} \left( X \cdot \sum_{i, \text{hadrons}} K(\xi - \xi_i) e^{ik(\xi - \xi_i)} - \sum_{j, \text{electrons}} K(\xi - \xi_j) e^{ik(\xi - \xi_j)} \right)$$

$$E_o = 2G_o \cdot \gamma_o \cdot \frac{e}{\beta \epsilon_{\perp n}}$$

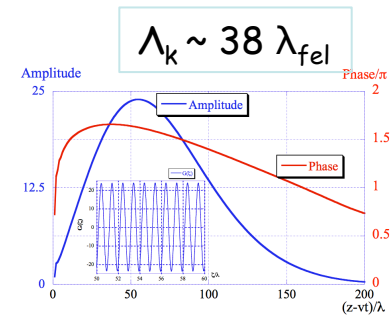
$$X = q/e \equiv Z(1 - \cos \varphi_1) \sim Z$$

Evolution of the RMS value resembles stochastic cooling!  
Best cooling rate achievable is  $\sim 1/N_{eff}$ ,  $N_{eff}$  is effective number of hadrons in coherent sample ( $\Lambda_k = N_c \lambda$ )

$$\langle \delta^2 \rangle' = -2\xi \langle \delta^2 \rangle + \mathbf{D}_{cec}$$

$$\Lambda_k = \iint |K(z - \zeta)|^2 d\zeta$$

$$N_{eff} \cong N_h \frac{\Lambda_k}{\sqrt{4\pi\sigma_{z,h}}} + \frac{N_e}{X^2} \frac{\Lambda_k}{\sqrt{4\pi\sigma_{z,e}}}$$



$$\xi = -g \langle \delta_i \text{Im}(K(\Delta \zeta_i) e^{ik\Delta \zeta_i}) \rangle / \langle \delta^2 \rangle;$$

$$\mathbf{D}_{cec} = g^2 N_{eff} / 2; \quad g = G_o \frac{Z^2}{A} \frac{r_p}{\epsilon_{\perp n}} \left\{ 2f(\varphi_2)(1 - \cos \varphi_1) \frac{l_2}{\beta} \right\},$$

$$\xi_{CeC}(\text{max}) \propto \frac{1}{N_{eff}}$$

$$\tau_{CeC} \propto \frac{1}{f \cdot N_{eff}} \sim 250 \text{ sec}$$

eRHIC @ 250 GeV -> FEL wavelength 0.5 um,  $\Lambda_k \sim 20 \text{ um}$ ,  $N_{eff} \sim 3 \times 10^7$  : it is critical to see if this can be achieved

$$\epsilon' / \epsilon = -2g + g^2 \rightarrow g \sim 1$$

CeC is novel and untested technique  
& clearly requires proof-of-principle facility

## Main Goals of CeC PoP experiment (KPP)

Demonstrate energy cooling with CeC

Compare with the theory and simulations

## Ultimate Goals of CeC PoP system (UPP)

Cool entire beam

Evaluate CeC performance

- Then (if possible)

- Use to test classical bunched electron cooling

- Use for advanced CeC tests

- Use for linac-ring beam-beam effects studies

- Use for bunch space-charge compensation experiment

# Dec. 4-5, 2012, External Review

Oliver Brüning (Chair), Valeri Lebedev, Robert Palmer, Hasam Padamsee

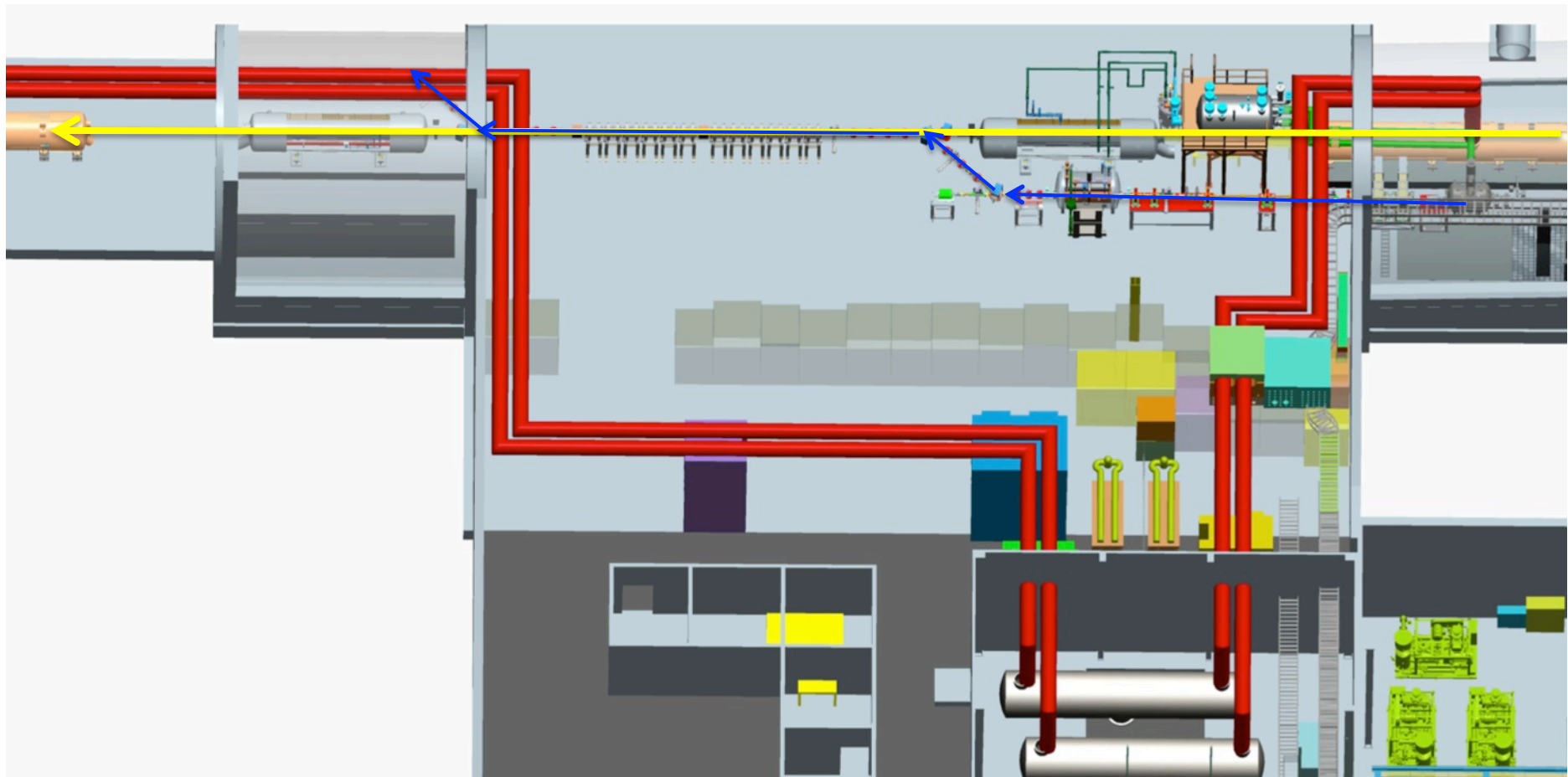
Start Time	Topic	Presenter	Duration
8:30	Executive Session		0:30
9:00	Welcome	T. Roser/I. Ben-Zvi	0:15
9:15	Coherent Electron Cooling	V.N. Litvinenko	0:30
9:45	CeC PoP Project Overview	I. Pinayev	0:30
10:15	CeC Analytical Modeling	G. Wang	0:30
10:45	Coffee Break		0:15
11:00	Numerical Simulations of CeC	K. Paul, Tech X	0:30
11:30	e-Beam Dynamics in CeC accelerator	D. Kayran	0:30
12:00	Drive Laser & Photocathode Development	B. Sheehy	0:30
12:30	Lunch		1:00
13:30	CeC PoP Engineering	J. Tuozzolo	0:25
13:55	SRF and RF systems for CeC PoP	S. Belomestnykh	0:25
14:20	RF transmitters and LLRF	A. Zaltsman	0:20
14:40	CeC PoP layout and design	J.C. Brutus	0:20
15:00	Coffee Break		0:15
15:15	Cryogenic System for CeC PoP	P. Orfin / J.Huan	0:30
15:45	CeC PoP beamline	G. Mahler	0:30
16:15	Diagnostics	T. Miller	0:25
16:40	Control System for CeC PoP Experiment	K. Brown	0:20
17:00	Executive Session		1:15

## *Executive Summary*

Coherent Electron Cooling (CeC) is a very appealing fundamentally new concept that could offer an impressive increase in cooling power for high energy bunched hadron beams (e.g. three orders of magnitude wrt stochastic cooling in RHIC). The CeC PoP is a major component of the R&D for a high luminosity Electron-Ion Collider at BNL (eRHIC).

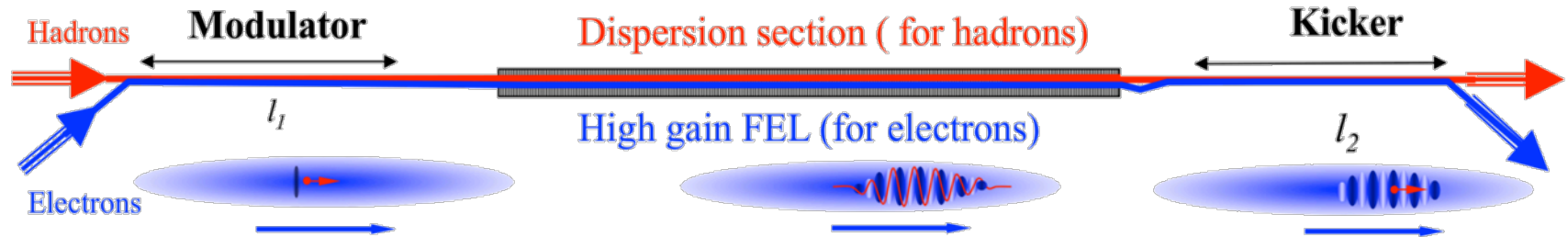
**Next DoE Review: Nov. 12, 2015**

# CeC Proof-of-Principle Experiment

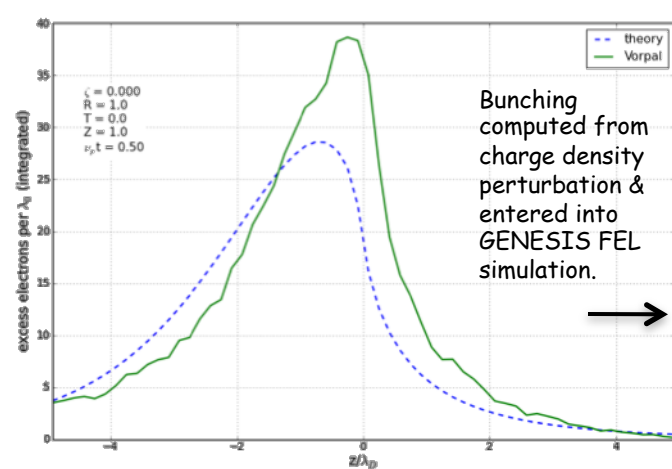


Coherent electron *Cooling* PoP

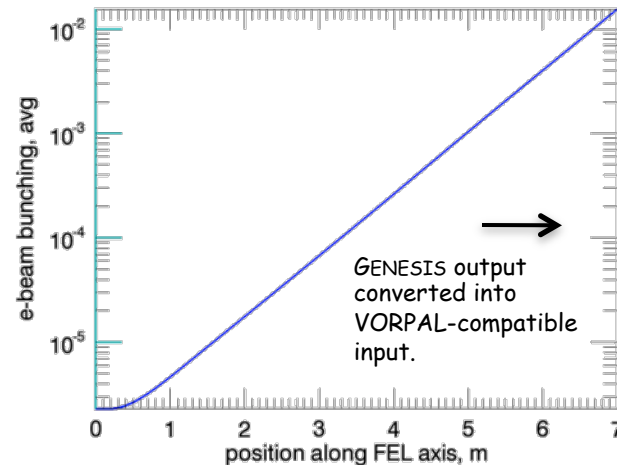
Our PoP is based on an economic version of CeC:  
it limits strength of the wiggler  $a_w$  to about 0.5  
but it is very cost effective



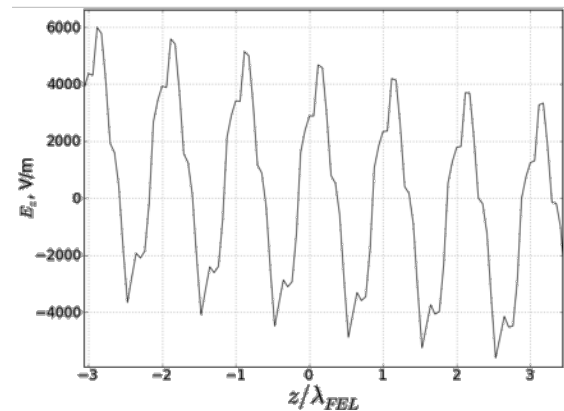
Param.'s from 40 GeV proof-of-principle exp. at BNL



VORPAL 3D  $\delta f$  PIC computation of e- density perturbation near  $Au^{79}$  ion (green) vs. idealized theory (blue). On Cray XE6 cluster at NERSC.



GENESIS parallel computation of electron beam bunching in free electron laser (FEL) shows amplification of modulator signal.



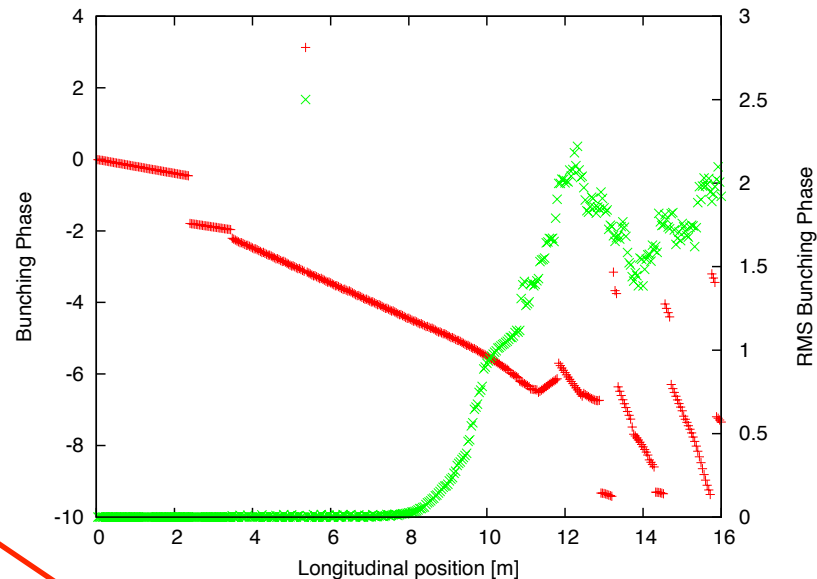
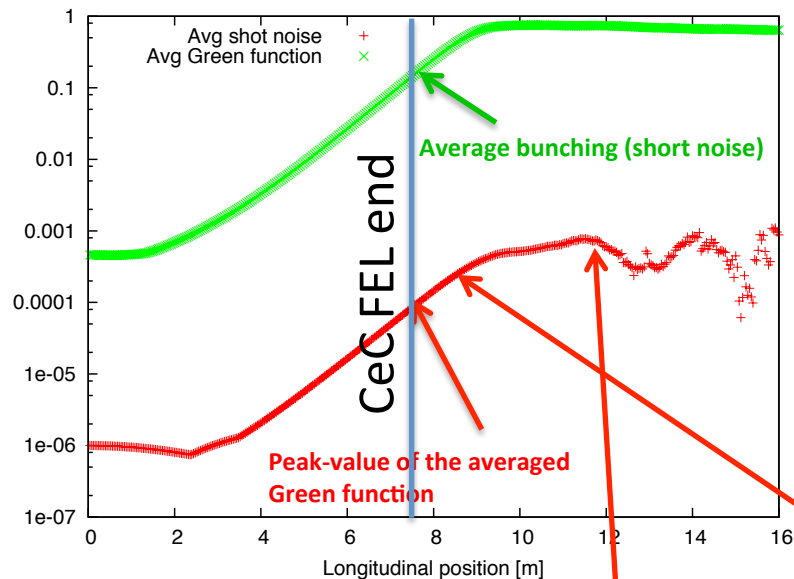
VORPAL prediction of the coherent kicker electric field  $E_k$  due to e-density perturbation from modulator, amplified in the FEL.

Simulations by Tech-X

# FEL saturation

## Bunching amplitude and phase (CeC PoP)

© Y. Jing



Signal grows exponentially until ~ 9 m with gain at 409 and it continues to grow and saturates with gain of 777 @ 11.5 m.

$$g_{\max} \sim 144 \cdot \sqrt{\frac{I_p[A] \cdot \lambda_o[\mu m]}{M_c}} = 858$$

10% difference between theoretical estimation and simulation

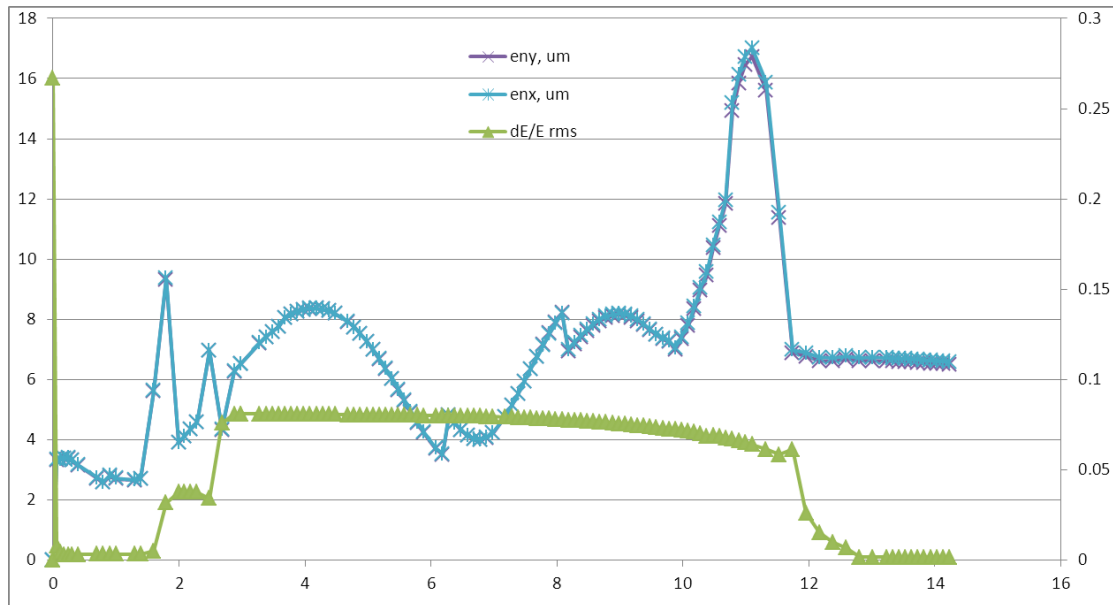
# Main Beam Parameters for CeC Experiment

Parameter	Value
Species in RHIC	Au <sup>+79</sup> ions, 40 GeV/u
Relativistic factor	42.96
Number of particles in bucket	10 <sup>9</sup>
Electron energy	21.95 MeV
Charge per e-bunch	0.5-5 nC
Rep-rate	78.17 kHz
Average e-beam current	0.39 mA
Electron beam power	8.6 kW

# Electron Beam and FEL Parameters for CeC PoP experiment

Electron Beam	
RMS Energy Spread	$\leq 1 \times 10^{-3}$
Normalized Emittance	$\leq 5 \text{ } \mu\text{m}\cdot\text{rad}$
Peak Current	60-100 A
FEL	
Wiggler Length	$3 \times 2.5 \text{ m}$
Wiggler Period	40 mm
Wiggler Strength, $a_w$	$0.5 +0.05/-0.1$
FEL Wavelength	$13.6 \text{ } \mu\text{m}$

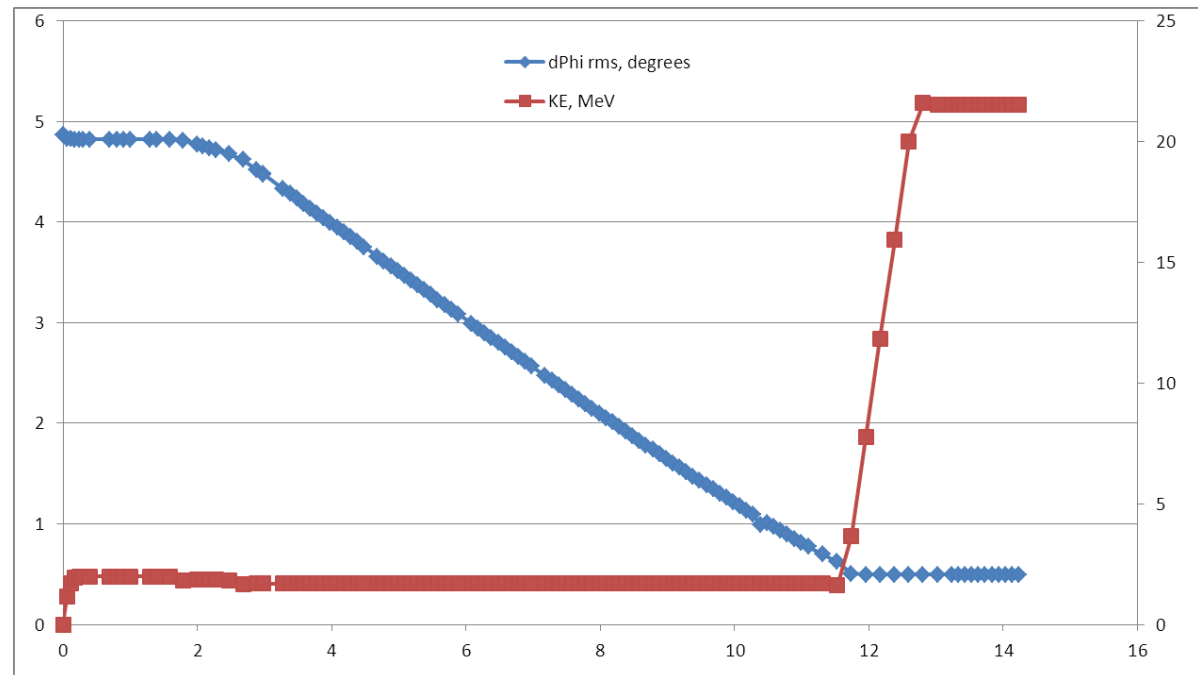
# Expected Electron Beam Parameters



Calculations are done for  
2 nC bunch  
Core charge is 1.3 nC  
Emittance is 8.6  $\mu\text{m}$ , core  
emittance is 3.3  $\mu\text{m}$

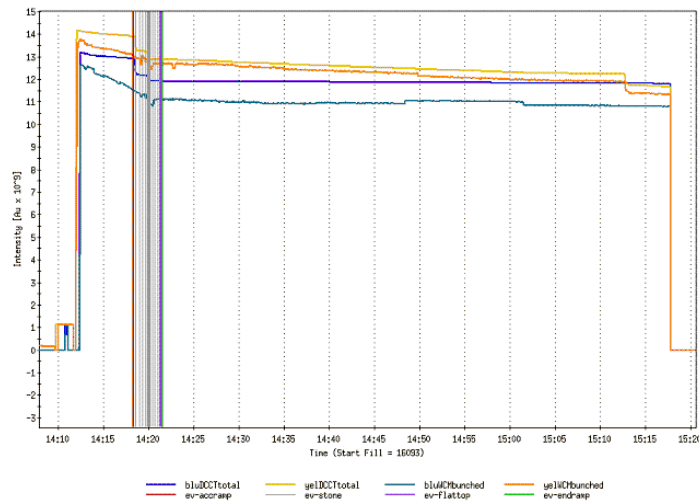
Relative energy spread is  
 $2 \times 10^{-3}$ , relative energy  
spread in the core is  
 $3 \times 10^{-4}$

Courtesy D. Kayran



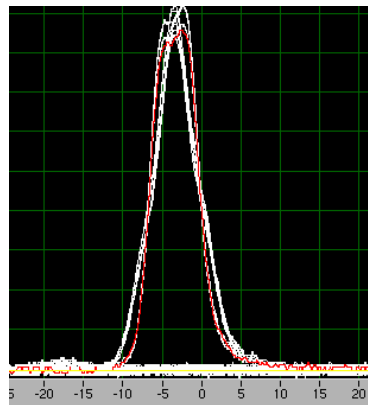
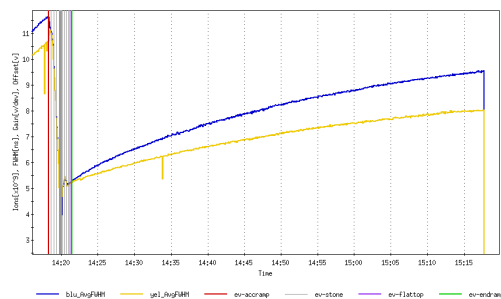
# CeC PoP RHIC Ramp Development

## Ramp : beam intensity

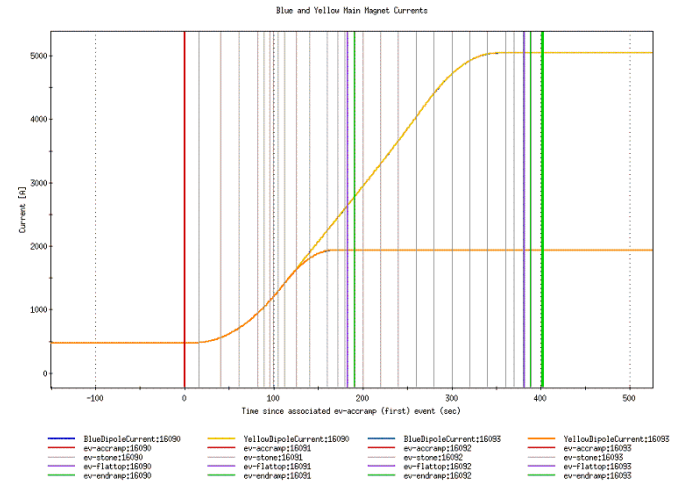


APEX on RUN 11: 2pm-4pm, June 20<sup>th</sup>, 2011 Fill: 16093

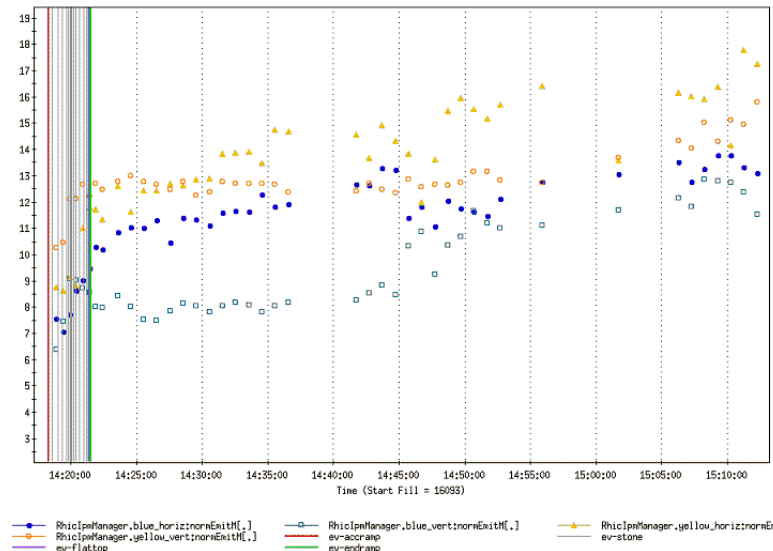
## Bunch length and profiles at 40 GeV



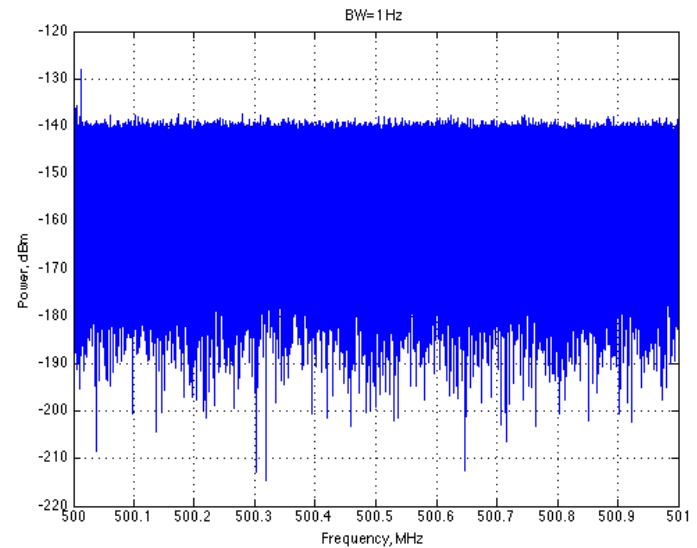
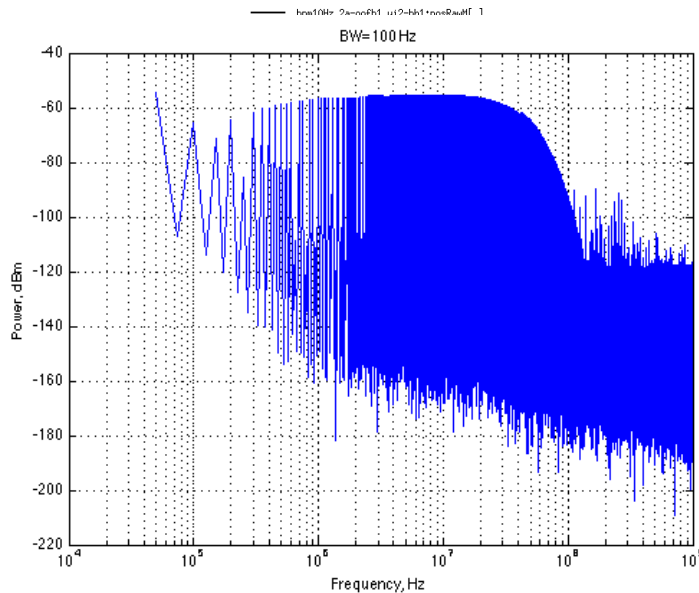
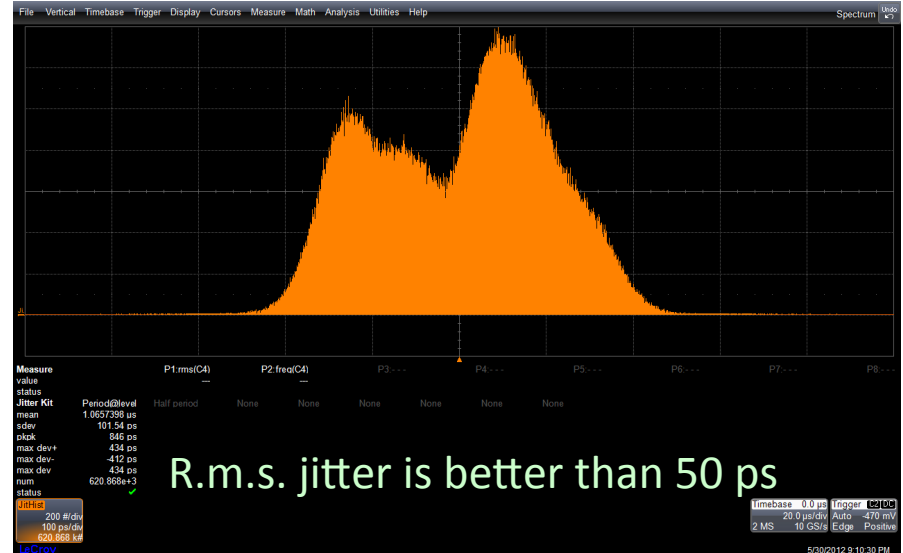
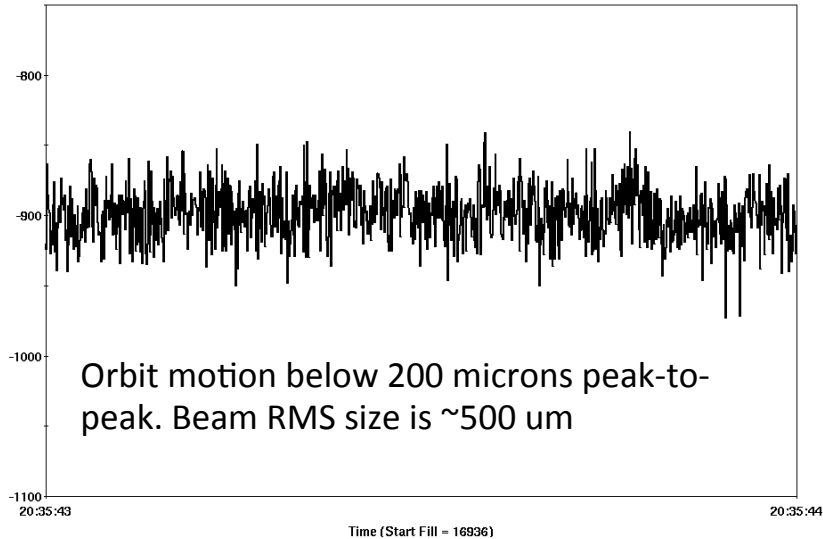
## Ramp : Magnets currents



## Emittance growth at 40 GeV



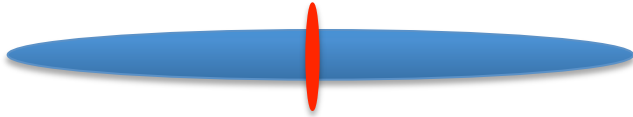
# Ion Beam Parameters Characterization



Noise floor is 80 dB below the signal at revolution frequency.

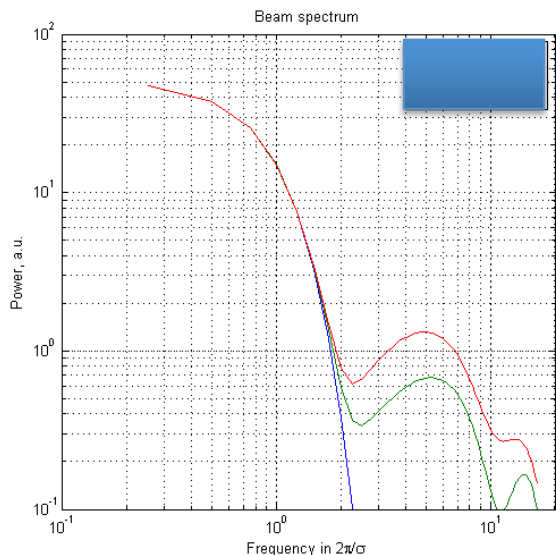
# Detecting CeC action

Electron bunch - 10 psec



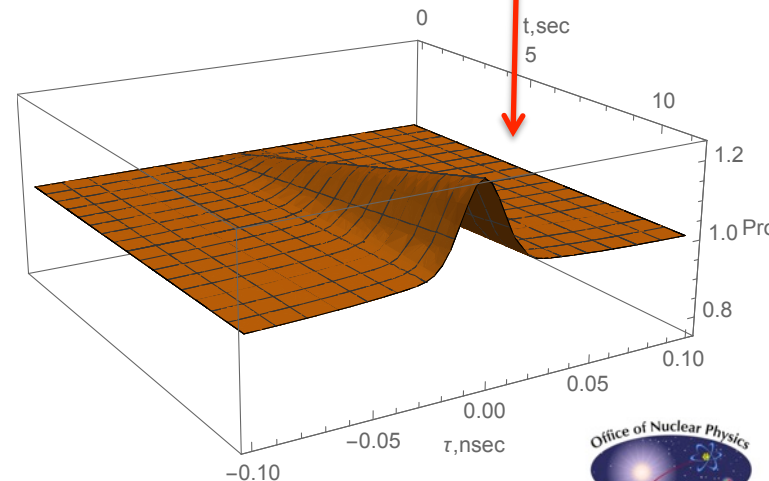
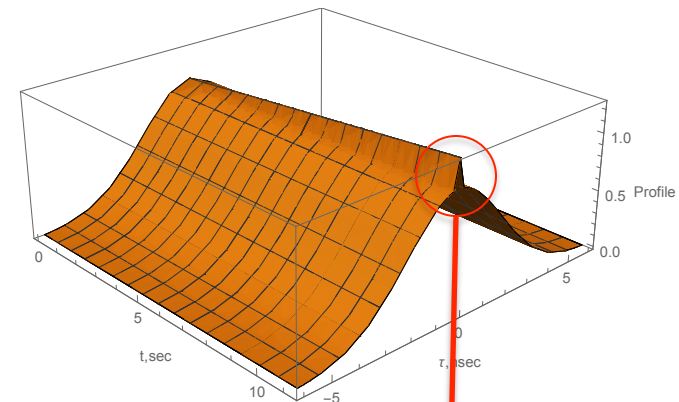
Ion bunch - 2 nsec

r.m.s. length of the cooled part 80-120 ps. The cooling effects can 2 GHz (or more) bandwidth using spectrum analyzer or digital scope

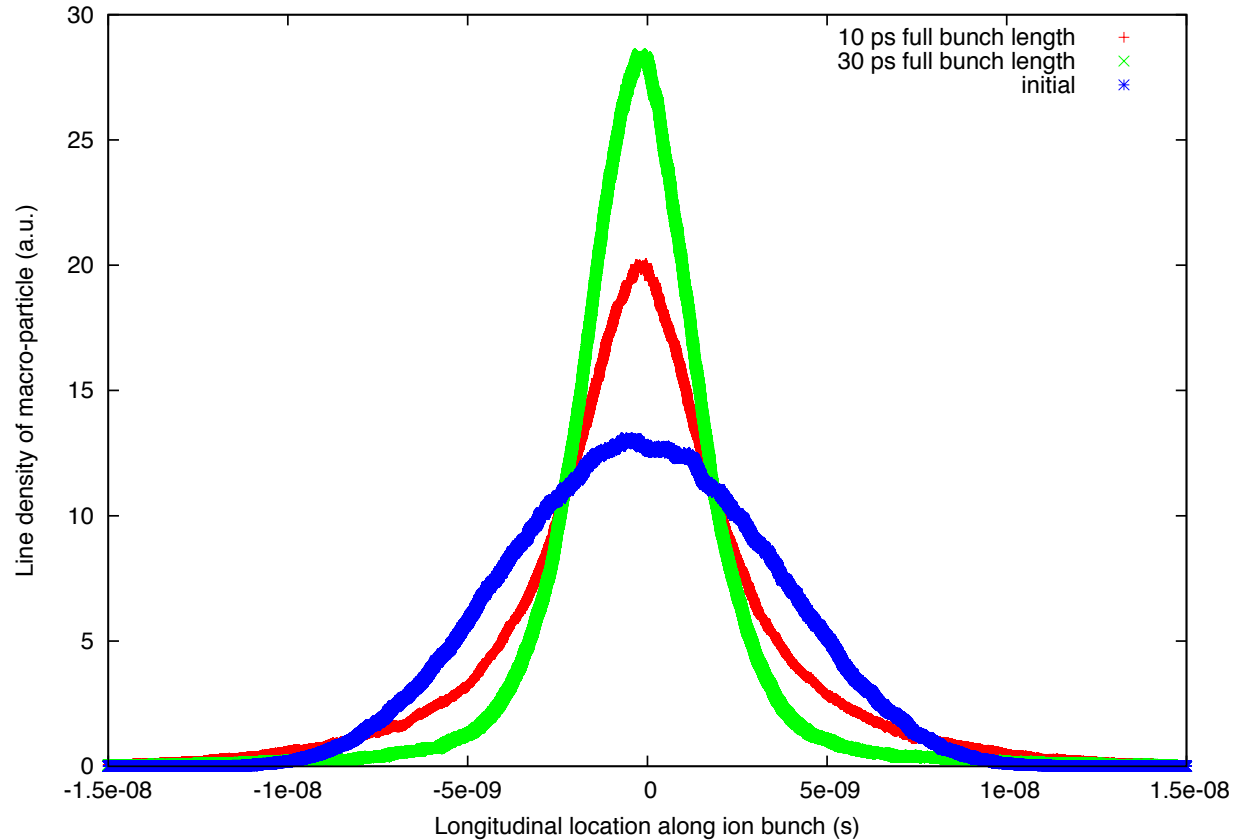


Well above noise floor

Simulated Au ion beam profile evolution with CeC PoP parameters



# Cooling full bunch Self-consistent simulations



Preliminary, © G.Wang

# View from Outer Space



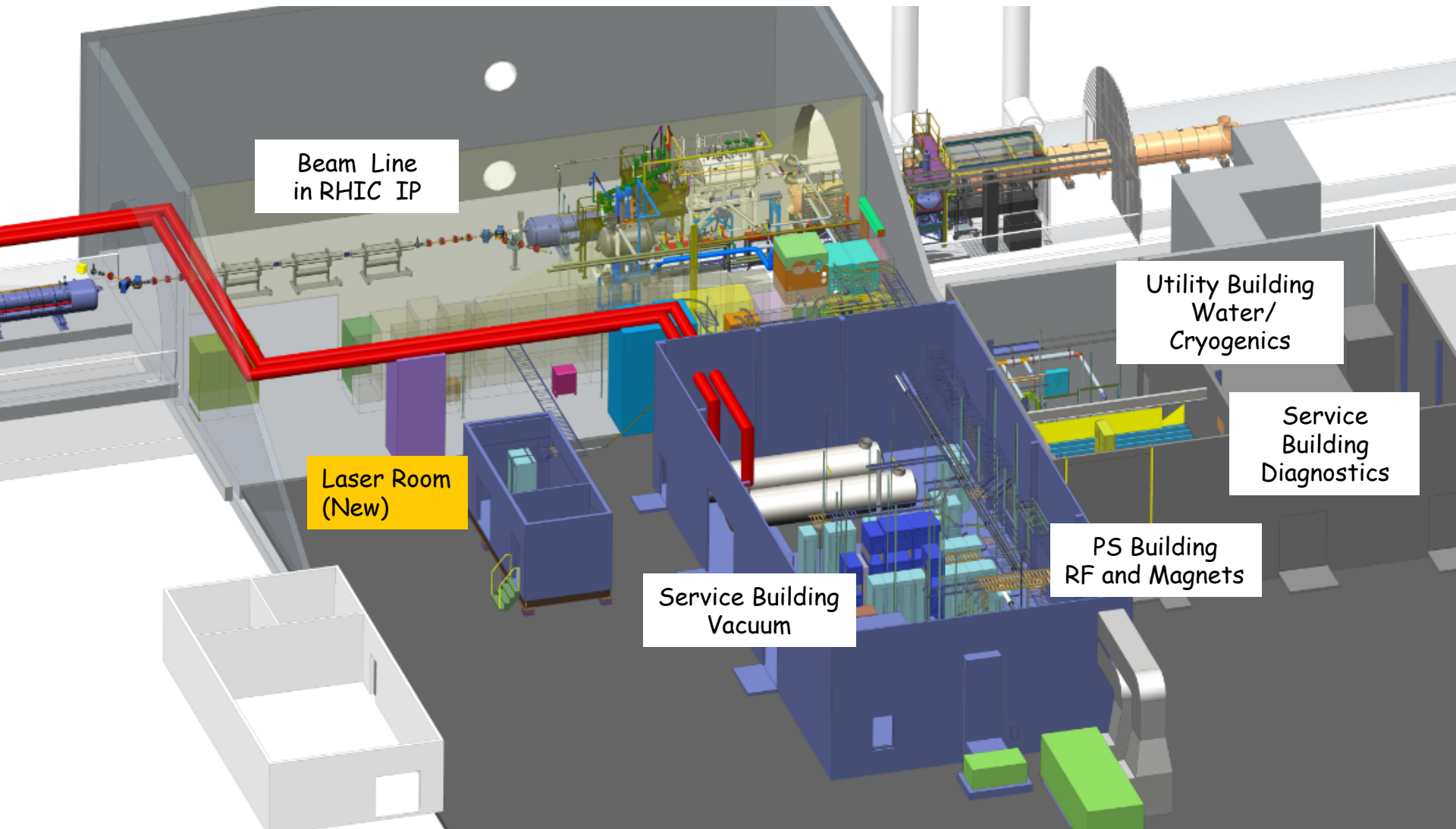
And from the ground



Location - RHIC 02:00 Region

Coherent electron *Cooling* PoP

# CeC PoP 3D rendering

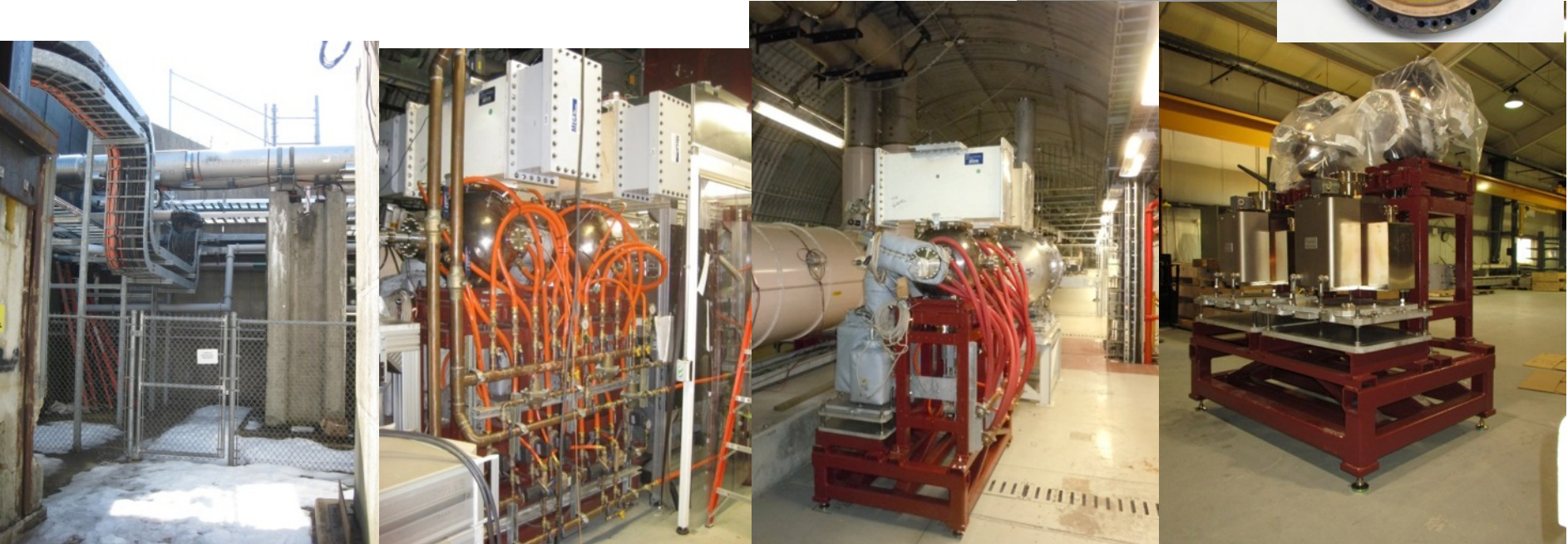


Coherent electron *Cooling* PoP

# Phase "0"

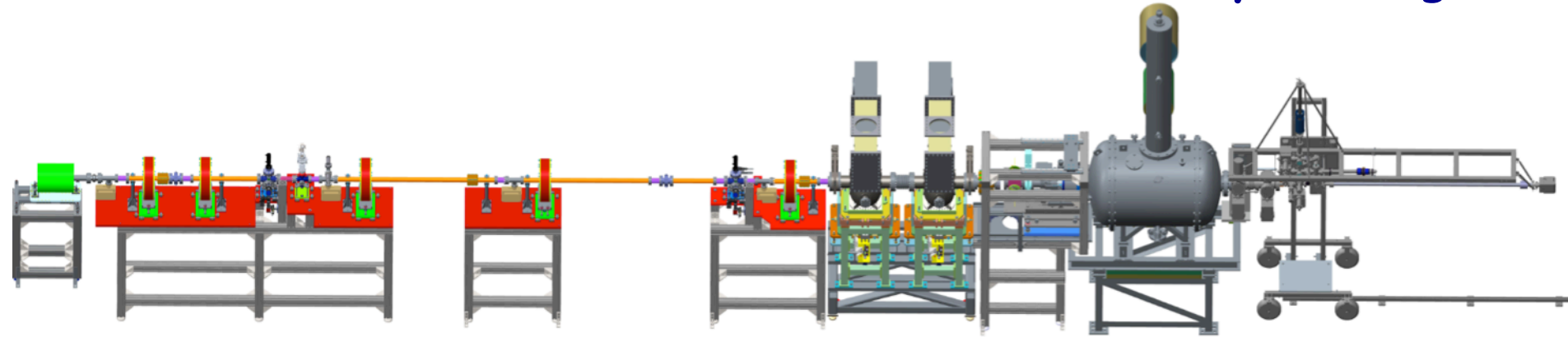
## Refurbish, Install and Test Buncher Cavities.

- Total rebuild: new cooling lines, cleaned and resealed windows, new seals, vacuum pumps and valves, rebuilt tuner drive.
- Cleanroom prepped and vacuum baked.
- New PA installed.
- New RF Coax installed.



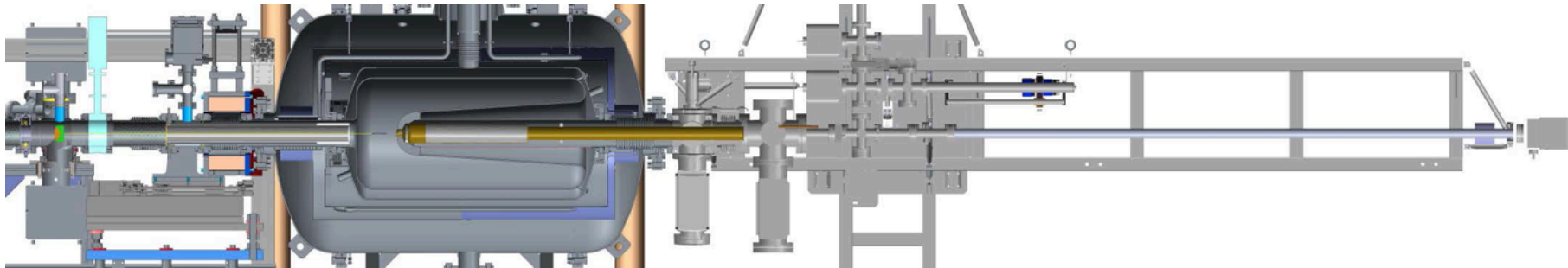
Coherent electron *Cooling* PoP

# Phase 1 - Beamline installation and 112 MHz Cavity Testing



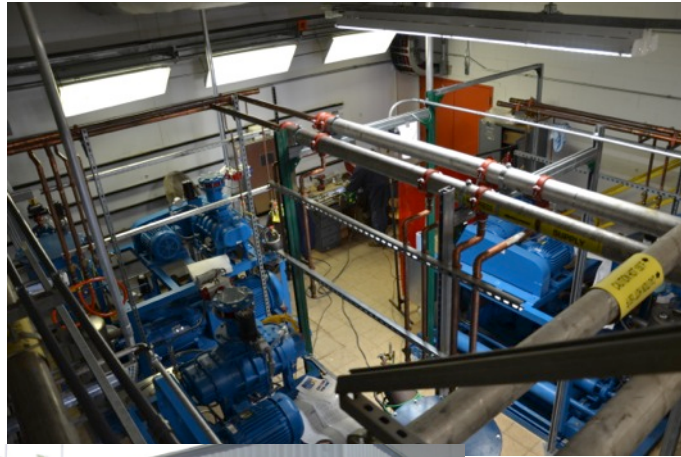
## CeC Phase 1 goals: 2014

- Install 112 MHz Cavity, Support Systems, and Cathode
- Install Beamline and Low Intensity Dump
- Make 112 MHz Cavity Cold and Test
  - (October 20) "dry run", ASSRC walk through
  - (October 27) cold test
  - (October 30) conditioning underway
  - (December 4) **2 MV !!**



Coherent electron *Cooling* PoP

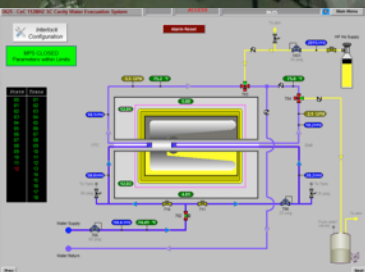
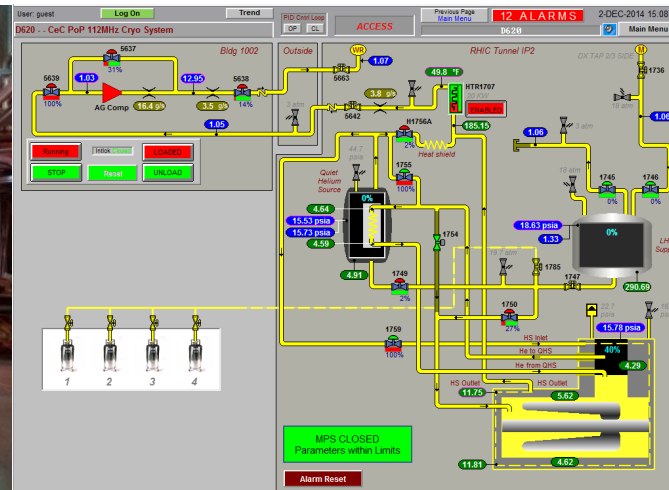
# Infrastructure



# 112 MHz Cavity Systems Installed and Tested

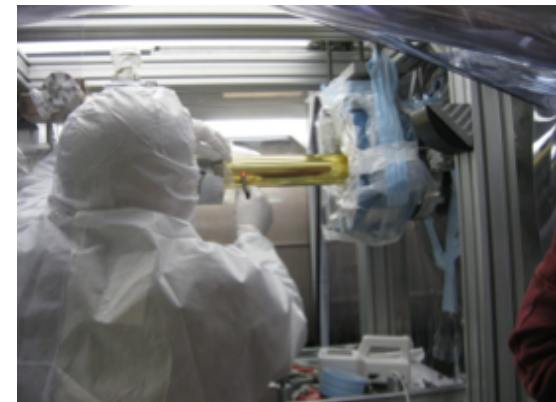
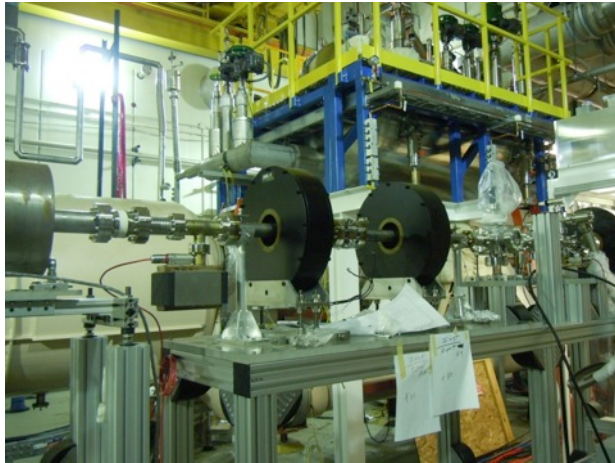
112 MHz Cavity Systems ready cryogenic operations:

- Quiet Helium heat exchanger delivered and installed.
- Helium recovery system installed and commissioned.
- Cryogenic control system operational.
- RF PA and associated systems installed and commissioned.
- Cathode stark and cathodes installed, aligned, and inserted.
- Cathode stark and FPC water systems operational and interlocked



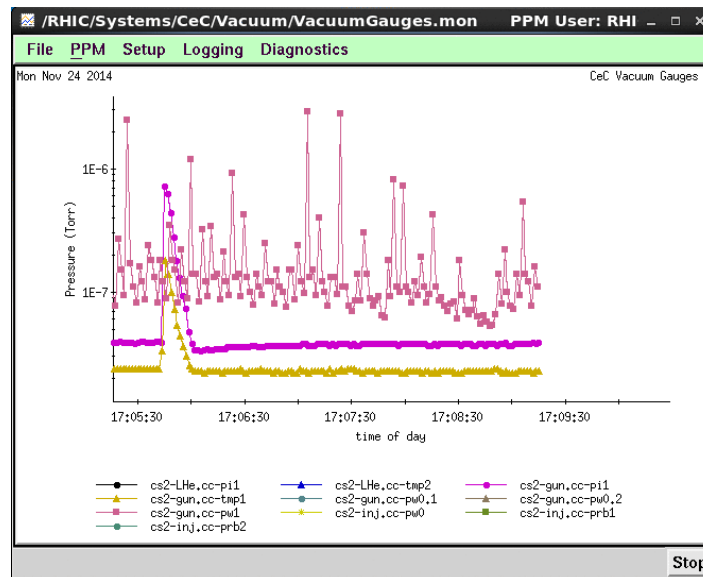
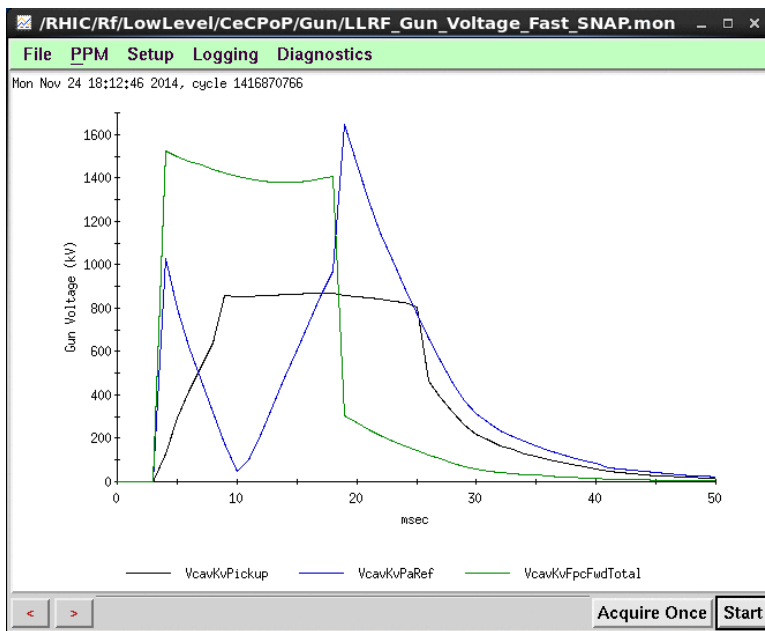
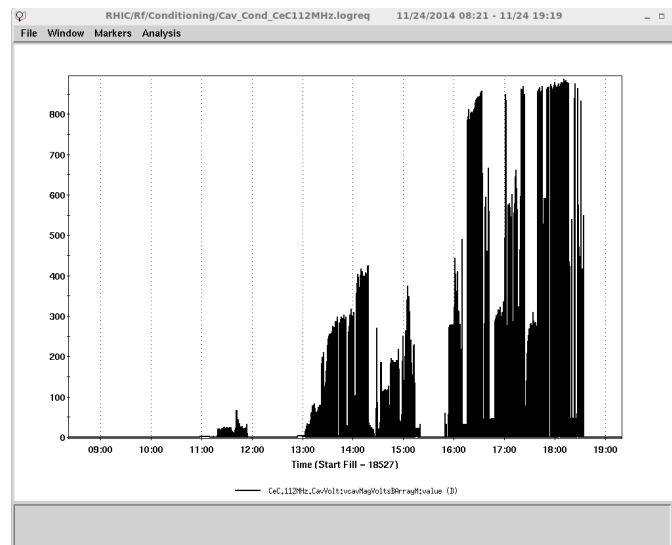
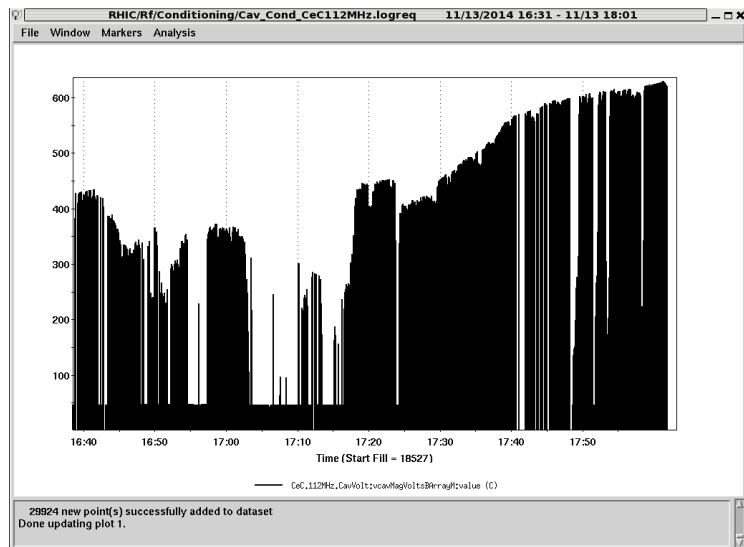
Coherent electron *Cooling* PoP

# IP2



Coherent electron *Cooling* PoP

# Conditioning 112 MHz Cavity



Coherent electron *Cooling* PoP

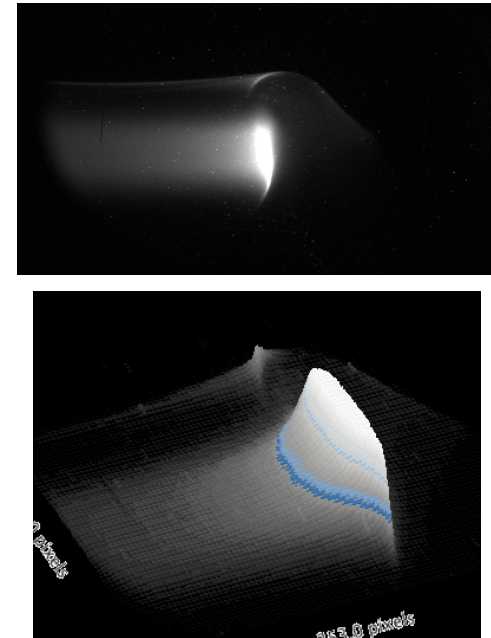
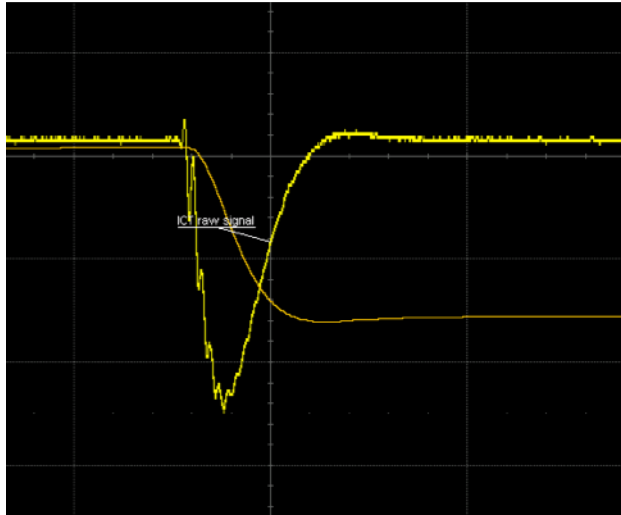
# First beam from 112 MHz gun - June 2015

1.6-1.7 MeV (kinetic energy) in CW mode

Laser generated CW e-Beam with 3 nC @ 5 kHz

2 MeV in pulse mode

25 MV/m at photocathode



## Milestones reported to DoE NP Q3 FY15

Demonstrating operation of 112 MHz SRF gun with 3 nC charge per bunch, 1.6 to 1.7 MeV kinetic energy in CW mode and above 2 MeV in pulsed mode.

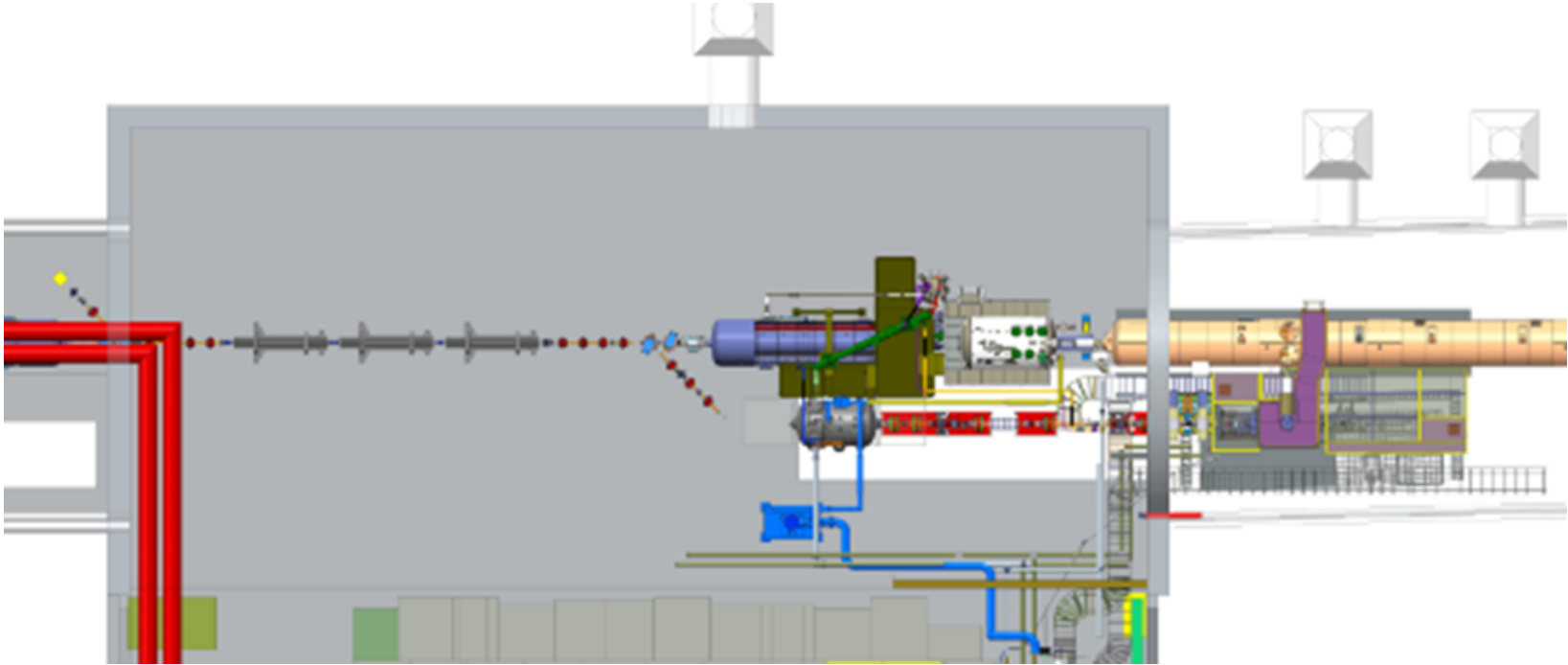
Production of high QE photocathodes for 112 MHz SRF gun.

Receiving helical wiggler system for CeC PoP FEL amplifier

Completion of the 704 MHz SRF linac cryo-module at NioWave Inc.

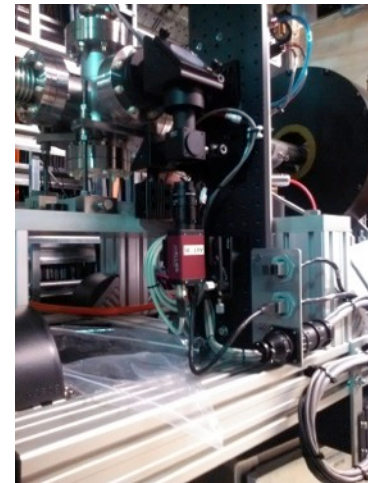
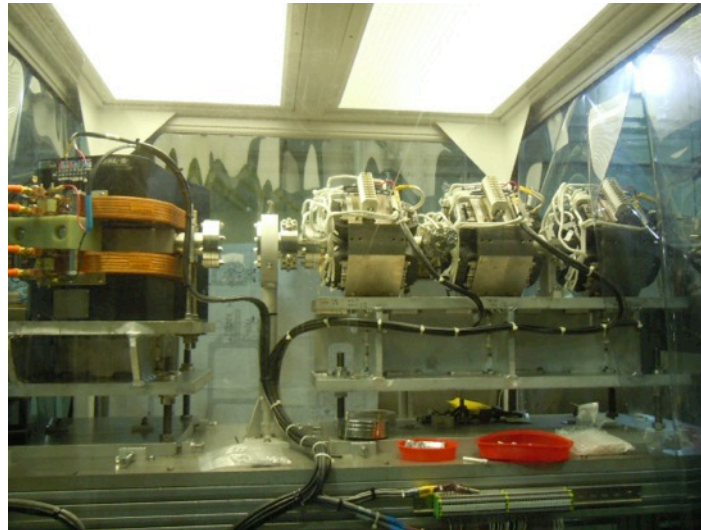
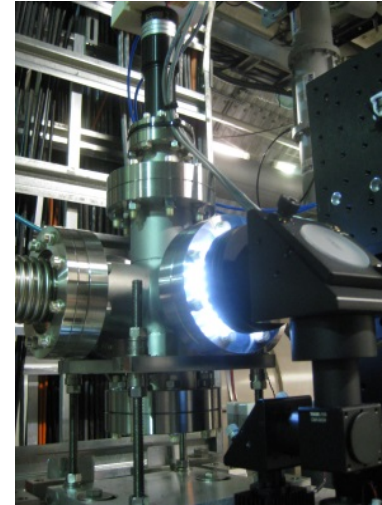
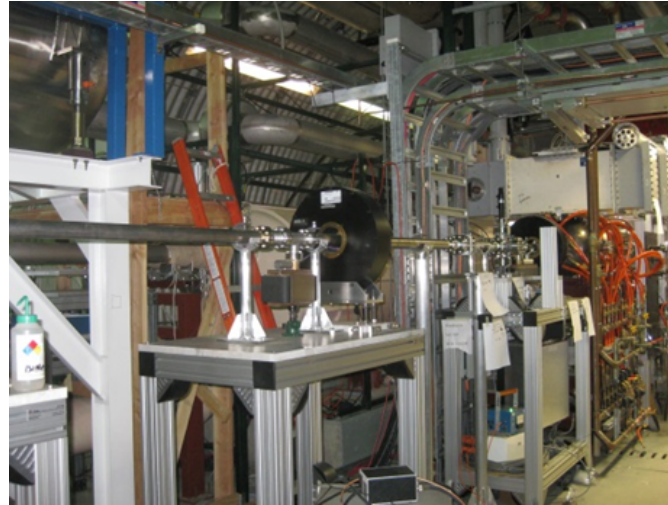
Completing the low energy transport beam line and its control system.

# Phase 3: Full Energy Beam Line Installation - 2015



- Install 704 MHz Systems and supporting cryogenic system
- Install Wiggler Magnets
- Install RHIC beam line components: dipoles, quads, correctors, vacuum
- Install beam diagnostics Modify and install RHIC DX-DO chamber for FEL light diagnostics
- Move CeC beam dump line to final location

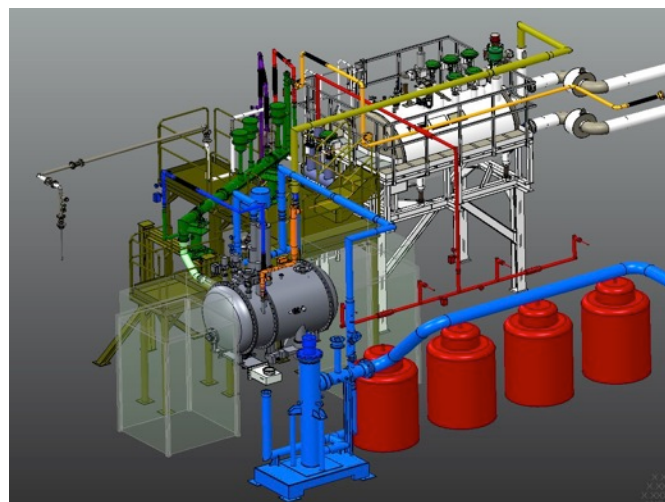
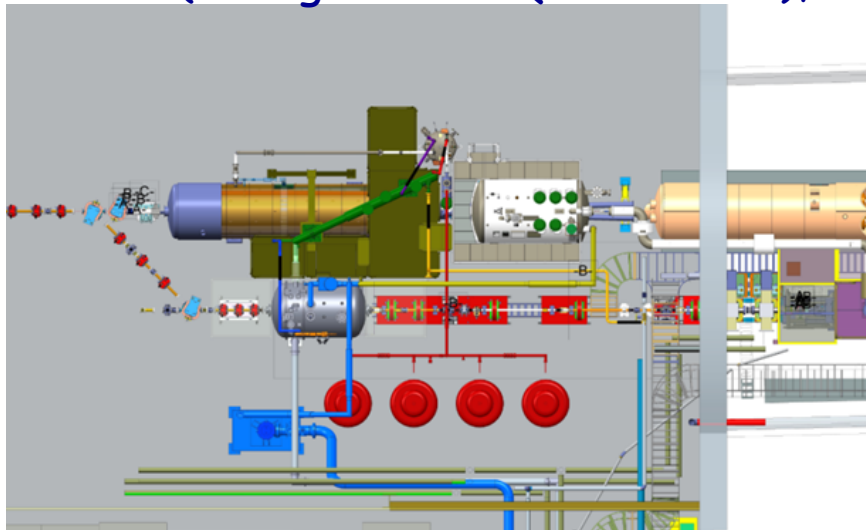
# Beamline Components



Coherent electron *Cooling* PoP

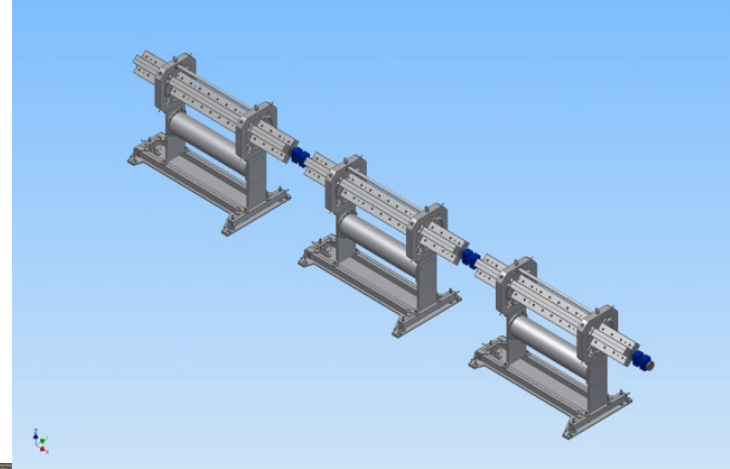
# 704 MHz SRF linac 2 K Cryogenics

- Integration with LEReC supply and return requirements complete
- All components ordered: VJP (green monster), heater return (blue), cooldown return (lime green to QHS heater), heater skid.



Coherent electron *Cooling* PoP

# Three Helical PM Wigglers at BNL from BINP (Novosibirsk). BINP team visited in July 2015



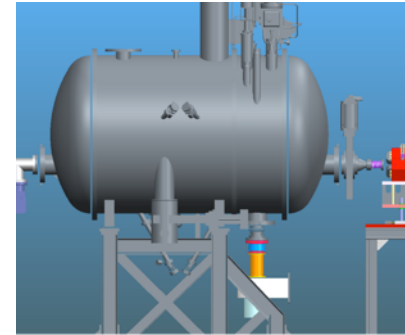
Left to right: Domenick Milidantry (SMD), Pavel Vobly (BINP), Ray Ceruti (SMD), Igor Ilin, Victor and Sergey Shadrin, Vitalii Zuev (all BINP) and Igor Pinayev (C-AD) near the first assembled helical wiggler

# Phase 3 - 704 MHz 5 Cell Cavity From Niowave

Delivery from Niowave - July 15, 2015

Coax in house being installed

FPC welding at AES is finished



704 MHz 5 Cell SRF linac  
(cryomodule)  
assembled at NioWave Inc



Cliff Brutus welcomes it at IP2

Coherent electron *Cooling* PoP

# Schedule

CeC PoP experiment is DoE NP's competitive R&D project –  
we are submitting quarterly progress and budget reports

Legend: x – milestone, **X** – major milestone

## Construction

Delivery of 704 MHz linac to BNL	<b>V</b>	30-Jul-15
Assembling and tuning helical wigglers	<b>V</b> 1/3	15-Aug-15
Install 704 MHz in RHIC tunnel	x	15-Nov-15
Install helical wigglers in RHIC tunnel	x	01-Dec-15
CW laser is commissioned	x	01-Dec-15
Beam diagnostics is intalled		15-Dec-15
Optical diagnostics is installed		15-Dec-15
<b>Complete CeC beam-line</b>	<b>X</b>	<b>15-Dec-15</b>

# Schedule for RHIC run 16

(dates are tentative and will be adjusted to RHIC Run 16)

Commissioning	Milestones		
SRF cavities cold	x	15-Feb-16	Has to be synchronized with RHIC run
<b>Complete cavity conditioning</b>	<b>X</b>	<b>15-Mar-16</b>	
<b>Generating first beam</b>	<b>X</b>	<b>01-Apr-16</b>	Assuming that SRF gun is working with photocathode pack
Measuring beam parameters	X	15-Apr-16	
Propagate beam to the beam dump	x	01-May-16	
<b>Test co-propagation with ion beam</b>	<b>X</b>	<b>15-May-16</b>	
<b>Demonstrate FEL amplification</b>	<b>X</b>	<b>01-Jun-16</b>	
<b>First cooling attempt</b>	<b>X</b>	<b>01-Jul-16</b>	Dedicated 5 days of running, dates have to be adjusted to the end of the RHIC run

This is very aggressive schedule aiming not only for commissioning of the CeC PoP system but also for detecting local cooling. Can be affected if p-A operation is scheduled for RHIC Run 16...

# Schedule - demonstration

(dates are tentative and will be adjusted to RHIC Run 17)

Making necessary up-grades/ improvements	01-Jul-16	31-Dec-16	Improving and updating diagnostics, optical system as well as installing buncher for ACeC test
SRF cavities cold	x	15-Feb-17	Has to be synchronized with RHIC run
<b>Complete cavity conditioning</b>	<b>X</b>	<b>01-Mar-17</b>	
<b>Recreating operational conditions</b>	<b>X</b>	<b>21-Mar-17</b>	
<b>Start CeC PoP experiments (using APEX shifts)</b>	<b>X</b>	<b>07-Apr-17</b>	
Demonstrate microbunching amplification (ACeC)	x	30-May-17	if time allows
<b>Demonstrate CeC PoP cooling</b>	<b>X</b>	<b>30-Jun-17</b>	
<b>CeC cooling experiments end</b>	<b>X</b>	<b>30-Jun-17</b>	Dates have to be adjusted to the end of the RHIC run

This schedule assumes that CeC systems are installed and commissioned with RHIC ion beam during RHIC run 16.

# Resource Loaded Schedule

WBS	Task Name	% Complete	Work	Cost	Start	Finish	2015					2016				2017					
							Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3			
1.	Coherent Electron Cooling (CeC) Experiment	10%	41,938 hrs	\$8,511,691	6/1/2015	7/28/2017															
1.1	Milestones	0%	0 hrs	\$0	6/15/2015	12/15/2015															
1.2	Project Management	0%	2,260 hrs	\$408,068	6/1/2015	12/31/2015															
1.3	Physics Support	0%	21,824 hrs	\$3,173,125	6/1/2015	7/28/2017															
1.4	SCRF Electron Gun	0%	0 hrs	\$0	7/1/2015	12/30/2015															
1.5	SCRF Linac Cavity	8%	264 hrs	\$590,322	6/1/2015	12/31/2015															
1.6	Buncher Cavity	100%	0 hrs	\$0	6/1/2015	6/1/2015															
1.7	Magnets + Power Supplies	10%	4,506 hrs	\$745,317	6/1/2015	12/28/2015															
1.8	Instrumentation Gassner	28%	1,216 hrs	\$551,478	6/1/2015	12/31/2015															
1.9	Beam Dump	0%	56 hrs	\$9,369	8/28/2015	9/23/2015															
1.10	Vacuum	0%	1,058 hrs	\$519,500	6/1/2015	11/30/2015															
1.11	Cryogenics	0%	2,076 hrs	\$326,730	6/1/2015	12/31/2015															
1.12	Controls Jamikowski	0%	934 hrs	\$224,058	6/1/2015	12/31/2015															
1.13	Civil Construction	100%	0 hrs	\$0	6/1/2015	6/1/2015															
1.14	Commissioning	0%	7,744 hrs	\$1,963,724	12/31/2015	7/26/2017															

Resource Name	Work	Cost
+ Building Trades-Riggers	42 hrs	\$6,466
+ Building Trades-Carpenters	84 hrs	\$12,932
+ Building Trades-Electricians	472 hrs	\$72,664
+ Central Shops	498 hrs	\$76,667
+ Designer	500 hrs	\$77,355
+ IT Professional	880 hrs	\$150,841
+ Admin	880 hrs	\$155,619
+ purchases < \$25K	178,414	\$276,542
+ Grad Student	10,560 hrs	\$316,800
+ Engineer	2,189 hrs	\$435,545
+ Technician	6,771 hrs	\$1,047,541
+ purchases > \$25k	893,000	\$1,062,670
+ Scientist	19,008 hrs	\$4,820,049

Project Name	CeC Experiment
Total FTEs	23.8
Unburdened Material Cost (k\$)	\$1,071

# Summary



- Progress continues on component installation and commissioning.
- 112 MHz generated electron beam during RHIC run 15
- Critical deliveries: 704 MHz cavity and undulator magnets
- Installation summer 2015
- Main uncertainty is introduced by potential p-A operation during Run16

# CeC PoP



**Where scientists and engineers  
work together !**

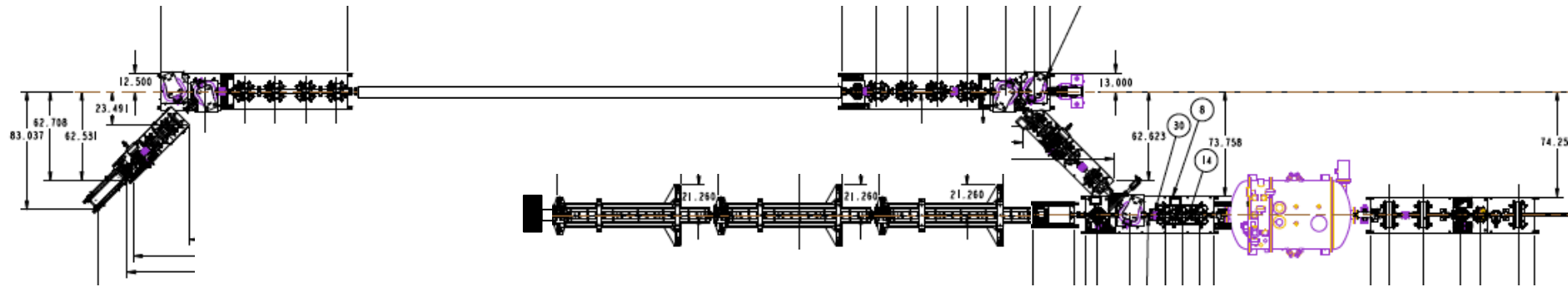
# Back-up slides

**In case p-A is inevitable**

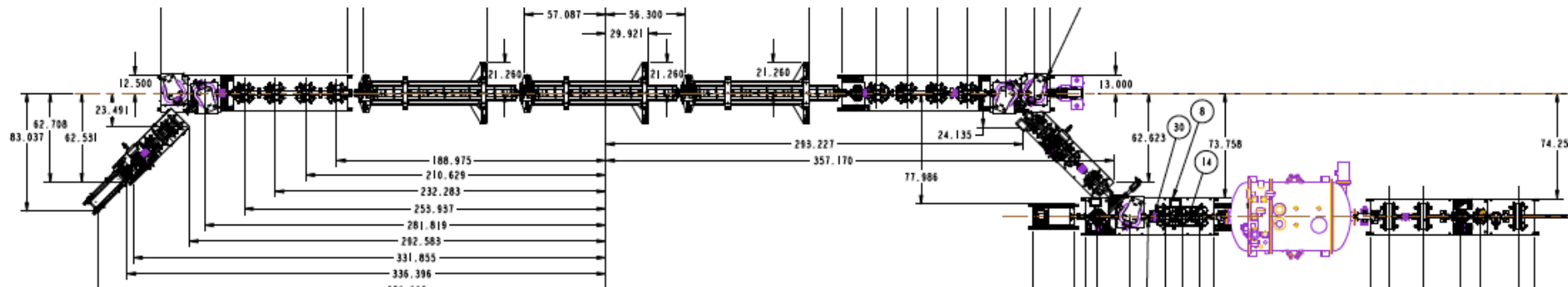
# Steps

1. Install the entire CeC beam-line and diagnostics, except the wiggler section
2. Install a NEG-coated pipe instead of the wiggler section
3. Propagate full power 20 MeV e-beam to the beam dump, can be used for testing bunched e-cooling
4. Install wiggler section in parallel to the IP2 and commission it with single shot (low power) beam and low power beam dump
5. At the end of the RHIC run - move the wiggler section in (3-4 days) and run CeC tests

# Initial configuration



# Final configuration



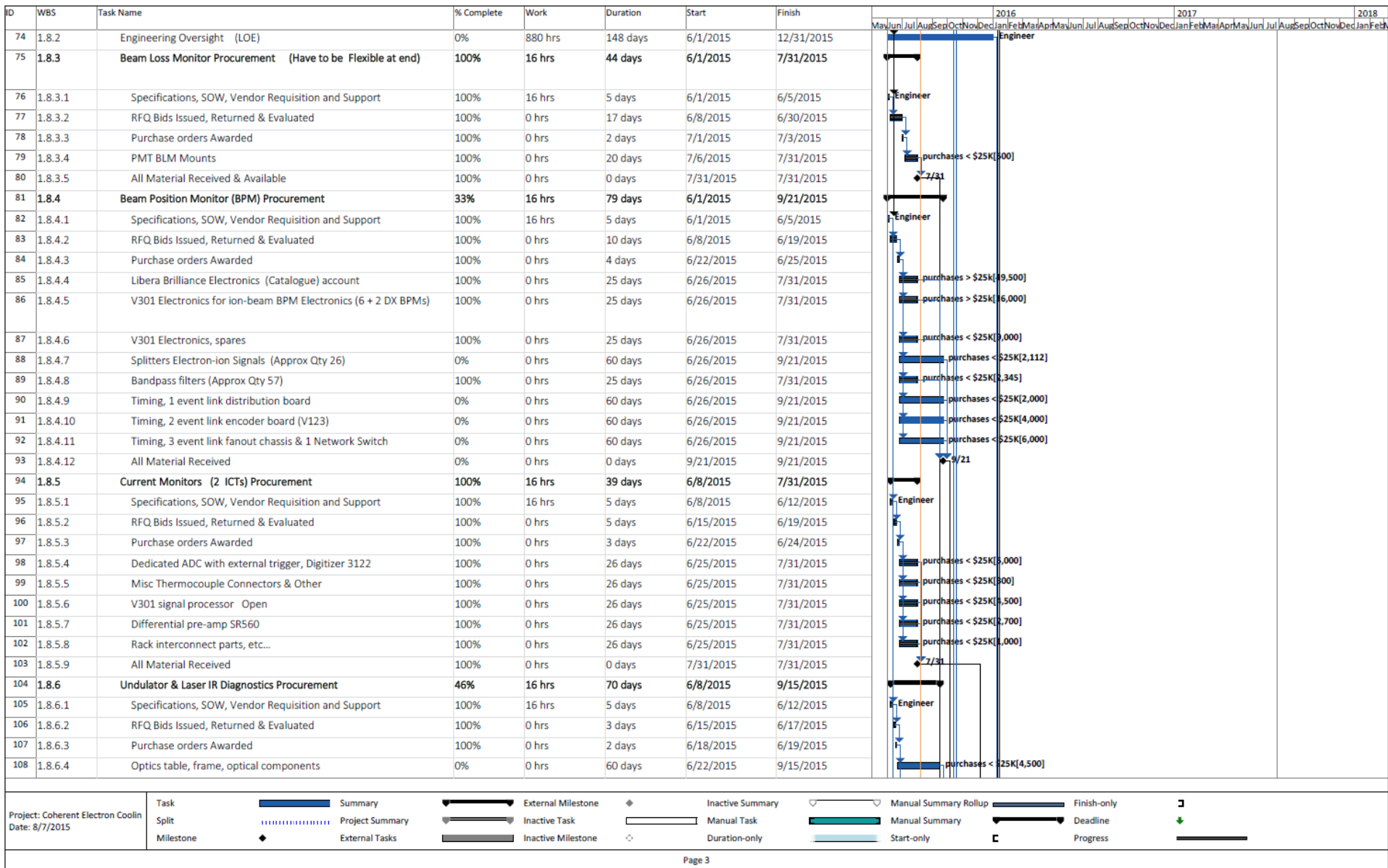
## Resource Loaded Schedule (Detail)

ID	WBS	Task Name	% Complete	Work	Duration	Start	Finish
0	1.	Coherent Electron Cooling (CeC) Experiment	10%	41,938 hrs	550 days	6/1/2015	7/28/2017
1	1.1	Milestones	0%	0 hrs	127 days	6/15/2015	12/15/2015
2	1.1.1	Attempt of generating beam from 112 MHz gun	0%	0 hrs	0 days	6/25/2015	6/25/2015
3	1.1.2	Delivery of 704 MHz linac to BNL	0%	0 hrs	0 days	6/15/2015	6/15/2015
4	1.1.3	Assembling and tuning helical wigglers	0%	0 hrs	0 days	8/15/2015	8/15/2015
5	1.1.4	Install 704 MHz in RHIC tunnel	0%	0 hrs	0 days	11/15/2015	11/15/2015
6	1.1.5	Install helical wigglers in RHIC tunnel	0%	0 hrs	0 days	12/1/2015	12/1/2015
7	1.1.6	CW laser is commissioned	0%	0 hrs	0 days	12/1/2015	12/1/2015
8	1.1.7	Beam diagnostics is intalled	0%	0 hrs	0 days	12/15/2015	12/15/2015
9	1.1.8	Optical diagnostics is installed	0%	0 hrs	0 days	12/15/2015	12/15/2015
10	1.1.9	Complete CeC beam-line	0%	0 hrs	0 days	12/15/2015	12/15/2015
11	1.2	Project Management	0%	2,260 hrs	148 days	6/1/2015	12/31/2015
12	1.3	Physics Support	0%	21,824 hrs	550 days	6/1/2015	7/28/2017
13	1.4	SCRF Electron Gun	0%	0 hrs	125 days	7/1/2015	12/30/2015
14	1.4.1	Specifications, SOW, Vendor Requisition and Support	0%	0 hrs	5 days	7/1/2015	7/8/2015
15	1.4.2	RFQ Bids Issued, Returned & Evaluated	0%	0 hrs	55 days	7/9/2015	9/24/2015
16	1.4.3	Purchase orders Awarded	0%	0 hrs	5 days	9/25/2015	10/1/2015
17	1.4.4	Cathodes	0%	0 hrs	60 days	10/2/2015	12/30/2015
18	1.4.5	All Purchases Received	0%	0 hrs	0 days	12/30/2015	12/30/2015
19	1.5	SCRF Linac Cavity	8%	264 hrs	148 days	6/1/2015	12/31/2015
20	1.5.1	704 MHz Cavity Start	0%	0 hrs	0 days	6/1/2015	6/1/2015
21	1.5.2	704 MHz Cavity Procurement	12%	16 hrs	103 days	6/1/2015	10/23/2015
22	1.5.2.1	Specifications, SOW, Vendor Requisition and Support	100%	16 hrs	2 days	6/1/2015	6/2/2015
23	1.5.2.2	RFQ Bids Issued, Returned & Evaluated	100%	0 hrs	0 days	6/2/2015	6/2/2015
24	1.5.2.3	Purchase orders Awarded	100%	0 hrs	0 days	6/4/2015	6/4/2015
25	1.5.2.4	704 MHz Cavity Delivered	100%	0 hrs	1 day	7/16/2015	7/16/2015
26	1.5.2.5	AES to Modify FPC	100%	0 hrs	13 days	7/1/2015	7/20/2015
27	1.5.2.6	Undulators	0%	0 hrs	40 days	7/20/2015	9/14/2015
28	1.5.2.7	704 MHz Cavity Work Platform	0%	0 hrs	40 days	8/28/2015	10/23/2015
29	1.5.2.8	View Port & Misc. Hardware	0%	0 hrs	35 days	6/5/2015	7/24/2015
30	1.5.2.9	All Purchases Received	0%	0 hrs	0 days	10/23/2015	10/23/2015
31	1.5.3	First Area Survey	0%	8 hrs	5 days	9/14/2015	9/18/2015
32	1.5.4	install Anchors	0%	16 hrs	5 days	9/21/2015	9/25/2015
33	1.5.5	Final Survey	0%	16 hrs	2 days	9/28/2015	9/29/2015
34	1.5.6	704 MHz Cavity & View Port Mod Installation	0%	28 hrs	5 days	9/30/2015	10/6/2015
35	1.5.7	704 MHz Cavity & View Port Mod Complete	0%	0 hrs	0 days	10/6/2015	10/6/2015
36	1.5.8	Work Platform Installed	0%	20 hrs	5 days	10/29/2015	11/4/2015

## Resource Loaded Schedule (Detail cont'd.)

ID	WBS	Task Name	% Complete	Work	Duration	Start	Finish
37	1.5.9	704 MHz Fundamental Power Coupler Installation	0%	80 hrs	5 days	11/5/2015	11/12/2015
38	1.5.10	FPC Vacuum, Cryo & RF Installed	0%	80 hrs	39 days	11/3/2015	12/31/2015
39	1.5.11	704 MHz Cavity Installation Complete	0%	0 hrs	0 days	12/31/2015	12/31/2015
40	1.6	Buncher Cavity	100%	0 hrs	0 days	6/1/2015	6/1/2015
41	1.6.1	Buncher Cavity (Complete)	100%	0 hrs	0 days	6/1/2015	6/1/2015
42	1.7	Magnets + Power Supplies	100%	4,506 hrs	145 days	6/1/2015	12/28/2015
43	1.7.1	Power Supplies Sert	100%	0 hrs	0 days	6/1/2015	6/1/2015
44	1.7.2	Power Supply Procurement	25%	2,312 hrs	124 days	6/1/2015	11/24/2015
45	1.7.2.1	Specifications, SOW, Vendor Requisition and Support	100%	16 hrs	0 days	6/1/2015	6/1/2015
46	1.7.2.2	RFQ Bids Issued, Returned & Evaluated	100%	0 hrs	0 days	6/15/2015	6/15/2015
47	1.7.2.3	Purchase orders Awarded	100%	0 hrs	0 days	6/15/2015	6/15/2015
48	1.7.2.4	Cabinets/Racks	100%	0 hrs	10 days	6/15/2015	6/26/2015
49	1.7.2.5	Cables	100%	0 hrs	10 days	6/15/2015	6/26/2015
50	1.7.2.6	All Material Received	100%	0 hrs	0 days	7/1/2015	7/1/2015
51	1.7.2.7	Install Trays and Power	0%	80 hrs	10 days	8/17/2015	8/28/2015
52	1.7.2.8	Install Cabinets	0%	40 hrs	10 days	9/8/2015	9/21/2015
53	1.7.2.9	Install PS October	0%	2,176 hrs	40 days	9/29/2015	11/24/2015
54	1.7.2.10	Power Supplies Installed	0%	0 hrs	0 days	11/24/2015	11/24/2015
55	1.7.3	Magnet Start	100%	0 hrs	0 days	6/1/2015	6/1/2015
56	1.7.4	Magnet Procurement	8%	16 hrs	55 days	6/1/2015	8/17/2015
57	1.7.4.1	Specifications, SOW, Vendor Requisition and Support	100%	16 hrs	0 days	6/1/2015	6/1/2015
58	1.7.4.2	RFQ Bids Issued, Returned & Evaluated	100%	0 hrs	0 days	6/8/2015	6/8/2015
59	1.7.4.3	Purchase orders Awarded	100%	0 hrs	10 days	6/8/2015	6/19/2015
60	1.7.4.4	45" Line Stand august	0%	0 hrs	40 days	6/22/2015	8/17/2015
61	1.7.4.5	Quards & Dipole Stand	0%	0 hrs	40 days	6/22/2015	8/17/2015
62	1.7.4.6	Misc. Hardware	0%	0 hrs	40 days	6/22/2015	8/17/2015
63	1.7.4.7	All Stands and Hardware Received	0%	0 hrs	0 days	8/17/2015	8/17/2015
64	1.7.5	Fabrication	0%	210 hrs	15 days	8/18/2015	9/8/2015
65	1.7.6	Magnet & Power Supply Installation	0%	1,968 hrs	91 days	8/17/2015	12/28/2015
66	1.7.6.1	First Area Survey August 15	0%	24 hrs	5 days	8/17/2015	8/21/2015
67	1.7.6.2	Install Anchors	0%	10 hrs	2 days	8/24/2015	8/25/2015
68	1.7.6.3	Install Stands	0%	1,824 hrs	55 days	9/9/2015	11/25/2015
69	1.7.6.4	Survey All Stands (4)	0%	30 hrs	15 days	11/27/2015	12/17/2015
70	1.7.6.5	Water Cooling for 4 Dipoles	0%	80 hrs	5 days	12/18/2015	12/28/2015
71	1.7.6.6	Magnet & Power Supplies Intallation Complete	0%	0 hrs	0 days	12/28/2015	12/28/2015
72	1.8	Instrumentation Gassner	28%	1,216 hrs	148 days	6/1/2015	12/31/2015
73	1.8.1	Instrumentation Start	0%	0 hrs	0 days	6/1/2015	6/1/2015

# Resource Loaded Schedule (Detail cont'd.)



## Resource Loaded Schedule (Detail cont'd.)

ID	WBS	Task Name	% Complete	Work	Duration	Start	Finish
109	1.8.6.5	Acton VM-504 Spectrometer	100%	0 hrs	29 days	6/22/2015	7/31/2015
110	1.8.6.6	Lock-in Amp for hi-res power meter, SR844	100%	0 hrs	29 days	6/22/2015	7/31/2015
111	1.8.6.7	3122 ADC, dedicated with external trigger	0%	0 hrs	60 days	6/22/2015	9/15/2015
112	1.8.6.8	Ophir - Pyrocam IR transverse beam profiler system	100%	0 hrs	29 days	6/22/2015	7/31/2015
113	1.8.6.9	One RADFET on the face of each undulator (3)	100%	0 hrs	29 days	6/22/2015	7/31/2015
114	1.8.6.10	RADFET signal processing	100%	0 hrs	29 days	6/22/2015	7/31/2015
115	1.8.6.11	Misc. cables & connectors for all	0%	0 hrs	60 days	6/22/2015	9/15/2015
116	1.8.6.12	All Material Received	0%	0 hrs	0 days	9/15/2015	9/15/2015
117	1.8.7	Dump Temperature Monitoring Procurement	0%	16 hrs	131 days	6/8/2015	12/11/2015
118	1.8.7.1	Specifications, SOW, Vendor Requisition and Support	0%	16 hrs	5 days	6/8/2015	6/12/2015
119	1.8.7.2	RFQ Bids Issued, Returned & Evaluated	0%	0 hrs	55 days	6/15/2015	8/31/2015
120	1.8.7.3	Purchase orders Awarded	0%	0 hrs	10 days	9/1/2015	9/15/2015
121	1.8.7.4	TC's	0%	0 hrs	60 days	9/16/2015	12/10/2015
122	1.8.7.5	Fiber optic signal Isolators	0%	0 hrs	60 days	9/16/2015	12/10/2015
123	1.8.7.6	level detectors	0%	0 hrs	60 days	9/16/2015	12/10/2015
124	1.8.7.7	Klixons	0%	0 hrs	60 days	9/16/2015	12/10/2015
125	1.8.7.8	All Material Received	0%	0 hrs	1 day	12/11/2015	12/11/2015
126	1.8.8	Motion Control Procurement	0%	16 hrs	130 days	6/8/2015	12/10/2015
127	1.8.8.1	Specifications, SOW, Vendor Requisition and Support	0%	16 hrs	5 days	6/8/2015	6/12/2015
128	1.8.8.2	RFQ Bids Issued, Returned & Evaluated	0%	0 hrs	55 days	6/15/2015	8/31/2015
129	1.8.8.3	Purchase orders Awarded	0%	0 hrs	10 days	9/1/2015	9/15/2015
130	1.8.8.4	Stepper Controller	0%	0 hrs	60 days	9/16/2015	12/10/2015
131	1.8.8.5	Piezo Controller	0%	0 hrs	60 days	9/16/2015	12/10/2015
132	1.8.8.6	Cables	0%	0 hrs	60 days	9/16/2015	12/10/2015
133	1.8.8.7	Rack Interconnected Parts	0%	0 hrs	60 days	9/16/2015	12/10/2015
134	1.8.8.8	All Material Received	0%	0 hrs	0 days	12/10/2015	12/10/2015
135	1.8.9	Instrumentation Installation	0%	240 hrs	79 days	9/8/2015	12/31/2015
136	1.8.9.1	Beam Loss Monitor & Beam Position Monitor Available	0%	0 hrs	0 days	9/21/2015	9/21/2015
137	1.8.9.2	Current & All Diagnostic Controls Available	0%	0 hrs	0 days	12/11/2015	12/11/2015
138	1.8.9.3	Survey Area	0%	40 hrs	5 days	9/8/2015	9/14/2015
139	1.8.9.4	Install BLM & BPoM	0%	68 hrs	5 days	9/22/2015	9/28/2015
140	1.8.9.5	Install Current Monitor & All Other Diagnostic Controls	0%	132 hrs	5 days	12/14/2015	12/18/2015
141	1.8.9.6	Instrumentation Complete	0%	0 hrs	0 days	12/31/2015	12/31/2015
142	1.9	Beam Dump	0%	56 hrs	18 days	8/28/2015	9/23/2015
143	1.9.1	Beam Dump Start Sept 1	0%	0 hrs	0 days	8/28/2015	8/28/2015
144	1.9.2	8.5 kW Beam Dump Installation	0%	56 hrs	18 days	8/28/2015	9/23/2015
145	1.9.2.1	First Area Survey	0%	8 hrs	5 days	8/28/2015	9/3/2015

## Resource Loaded Schedule (Detail cont'd.)

ID	WBS	Task Name	% Complete	Work	Duration	Start	Finish
146	1.9.2.2	Install Anchors	0%	2 hrs	2 days	9/4/2015	9/8/2015
147	1.9.2.3	Install Stand	0%	4 hrs	5 days	9/9/2015	9/15/2015
148	1.9.2.4	Assemble Dump to Stand	0%	6 hrs	2 days	9/16/2015	9/17/2015
149	1.9.2.5	Survey Stand & Dump	0%	8 hrs	2 days	9/18/2015	9/21/2015
150	1.9.2.6	Install cable tray-cables	0%	12 hrs	5 days	9/4/2015	9/11/2015
151	1.9.2.7	Assemble - Instrumentation	0%	8 hrs	2 days	9/22/2015	9/23/2015
152	1.9.2.8	Install Water Cooling	0%	8 hrs	2 days	9/22/2015	9/23/2015
153	1.9.2.9	Beam Dump Intallation Complete	0%	0 hrs	0 days	9/23/2015	9/23/2015
154	1.10	Vacuum Mapes Material in house??	0%	1,058 hrs	127 days	6/1/2015	11/30/2015
155	1.10.1	Vacuum Start	0%	0 hrs	0 days	6/1/2015	6/1/2015
156	1.10.2	Vacuum Procurement	0%	8 hrs	94 days	6/1/2015	10/12/2015
157	1.10.2.1	Specifications, SOW, Vendor Requisition and Support	0%	8 hrs	2 days	6/1/2015	6/2/2015
158	1.10.2.2	RFQ Bids Issued, Returned & Evaluated	0%	0 hrs	50 days	6/3/2015	8/12/2015
159	1.10.2.3	Purchase orders Awarded	0%	0 hrs	2 days	8/13/2015	8/14/2015
160	1.10.2.4	Valves 2 5" RF shielded valves and 1 2.5"RF shielded valve	0%	0 hrs	40 days	8/17/2015	10/12/2015
161	1.10.2.5	Bellows shielded in transport and RHIC beamline	0%	0 hrs	40 days	8/17/2015	10/12/2015
162	1.10.2.6	Adapters 45 degree dipole to RHIC warm vacuum chamber (need 2)	0%	0 hrs	40 days	8/17/2015	10/12/2015
163	1.10.2.7	Bellows T assembly for DX-DO chamber	0%	0 hrs	40 days	8/17/2015	10/12/2015
164	1.10.2.8	Optical table frame and hardware	0%	0 hrs	40 days	8/17/2015	10/12/2015
165	1.10.2.9	Misc. Material	0%	0 hrs	40 days	8/17/2015	10/12/2015
166	1.10.2.10	All Purchases Received	0%	0 hrs	0 days	10/12/2015	10/12/2015
167	1.10.3	Install RF Shields in Tees, Machine and Weld	0%	50 hrs	5 days	10/13/2015	10/19/2015
168	1.10.4	Undulator to beamline transition weldment	0%	50 hrs	5 days	10/13/2015	10/19/2015
169	1.10.5	NEG Coating Chamber	0%	200 hrs	15 days	10/13/2015	11/2/2015
170	1.10.6	Installation	0%	750 hrs	33 days	10/13/2015	11/30/2015
171	1.10.6.1	Beam line installation	0%	500 hrs	18 days	11/3/2015	11/30/2015
172	1.10.6.2	704 Clean Room Installation	0%	250 hrs	20 days	10/13/2015	11/9/2015
173	1.11	Cryogenics	0%	2,076 hrs	148 days	6/1/2015	12/31/2015
174	1.11.1	Cryo Installation Start	0%	0 hrs	0 days	6/1/2015	6/1/2015
175	1.11.2	Tech Support (LOE)	0%	1,760 hrs	148 days	6/1/2015	12/31/2015
176	1.11.3	Complete 8" Vacuum Line (Instrumentation, valve controls)	0%	144 hrs	104 days	6/1/2015	10/26/2015
177	1.11.3.1	Cryo Vacuum Line Procurement	0%	8 hrs	2 days	6/1/2015	6/3/2015
178	1.11.3.1.1	Specifications, SOW, Vendor Requisition and Support	100%	8 hrs	0 days	6/1/2015	6/1/2015
179	1.11.3.1.2	RFQ Bids Issued, Returned & Evaluated	100%	0 hrs	0 days	6/3/2015	6/3/2015
180	1.11.3.1.3	Purchase orders Awarded	100%	0 hrs	0 days	6/1/2015	6/1/2015

The Gantt chart displays the project schedule for the Coherent Electron Coolin project. It shows various tasks as horizontal bars spanning different periods from May 2015 to February 2018. Key milestones like 'Cryo Installation Start' and 'Complete 8" Vacuum Line' are highlighted. The chart uses a color-coded system to distinguish between different types of tasks and their completion status.

Project: Coherent Electron Coolin  
Date: 8/7/2015

Task		Summary		External Milestone		Inactive Summary		Manual Summary Rollup		Finish-only		Deadline
Split		Project Summary		Inactive Task		Manual Task		Manual Summary		Progress		
Milestone		External Tasks		Inactive Milestone		Duration-only		Start-only				

Page 5

## Resource Loaded Schedule (Detail cont'd.)

[illegible]

## Resource Loaded Schedule (Detail cont'd.)

ID	WBS	Task Name	% Complete	Work	Duration	Start	Finish
215	1.11.6.2	Build & Install Supports/Floor anchors & 704 MHz Cryo System Wiring	0%	16 hrs	2 days	10/21/2015	10/22/2015
216	1.12	Controls Jamikowski	0%	934 hrs	148 days	6/1/2015	12/31/2015
217	1.12.1	Controls Start	0%	0 hrs	0 days	6/1/2015	6/1/2015
218	1.12.2	Engineering Support	0%	880 hrs	148 days	6/1/2015	12/31/2015
219	1.12.3	Controls Procurement	0%	54 hrs	130 days	6/1/2015	12/3/2015
220	1.12.3.1	Specifications, SOW, Vendor Requisition and Support	0%	2 hrs	5 days	6/1/2015	6/5/2015
221	1.12.3.2	RFQ Bids Issued, Returned & Evaluated	0%	50 hrs	60 days	6/8/2015	8/31/2015
222	1.12.3.3	Purchase orders Awarded	0%	2 hrs	5 days	9/1/2015	9/8/2015
223	1.12.3.4	WS-C3750X-48T-L 3 @ \$5,700 each	0%	0 hrs	60 days	9/9/2015	12/3/2015
224	1.12.3.5	Cisco StackWise 50CM Stacking Cable 3 @ \$63 each	0%	0 hrs	60 days	9/9/2015	12/3/2015
225	1.12.3.6	Cat3k-x 350W ac p/s 3 @ \$318 each	0%	0 hrs	60 days	9/9/2015	12/3/2015
226	1.12.3.7	cat3k-x 1gb network module 3 @ \$314 each	0%	0 hrs	60 days	9/9/2015	12/3/2015
227	1.12.3.8	2960 edge switches for BPM's and controls area expansion	0%	0 hrs	60 days	9/9/2015	12/3/2015
228	1.12.3.9	2960s 48 port 4x sfp lan base 4 @ \$2,628 each	0%	0 hrs	60 days	9/9/2015	12/3/2015
229	1.12.3.10	stack cable 1M 4 @ \$124 each	0%	0 hrs	60 days	9/9/2015	12/3/2015
230	1.12.3.11	flexstack module 4 @ \$757 each	0%	0 hrs	60 days	9/9/2015	12/3/2015
231	1.12.3.12	All Material Received	0%	0 hrs	0 days	12/3/2015	12/3/2015
232	1.13	Civil Construction	100%	0 hrs	0 days	6/1/2015	6/1/2015
233	1.14	Commissioning	0%	7,744 hrs	400 days	12/31/2015	7/26/2017
234	1.14.1	Physics Support	0%	7,744 hrs	20 mons	12/31/2015	7/26/2017
235	1.14.2	Milestones Needs (fine tuning)	0%	0 hrs	126.5 days	12/31/2015	7/1/2016
236	1.14.2.1	Installation Complete	0%	0 hrs	0 days	12/31/2015	12/31/2015
237	1.14.2.2	SRF cavities cold (Note) Jan 15	0%	0 hrs	0 days	2/15/2016	2/15/2016
238	1.14.2.3	Complete cavity conditioning	0%	0 hrs	0 days	3/15/2016	3/15/2016
239	1.14.2.4	Generating fist beam (Note)	0%	0 hrs	0 days	4/1/2016	4/1/2016
240	1.14.2.5	Measuring beam parameters	0%	0 hrs	0 days	4/15/2016	4/15/2016
241	1.14.2.6	Propagate beam to the beam dump	0%	0 hrs	0 days	5/1/2016	5/1/2016
242	1.14.2.7	Start CeC PoP experiments (using APEX shifts)	0%	0 hrs	0 days	5/13/2016	5/13/2016
243	1.14.2.8	Demonstrate FEL amplification	0%	0 hrs	0 days	5/27/2016	5/27/2016
244	1.14.2.9	Test co-propagation with ion beam	0%	0 hrs	0 days	7/1/2016	7/1/2016
245	1.14.2.10	Demonstrate FEL amplification	0%	0 hrs	0 days	6/1/2016	6/1/2016
246	1.14.2.11	First cooling attempt (Note) 6/15/16	0%	0 hrs	0 days	7/1/2016	7/1/2016

Project: Coherent Electron Coolin Date: 8/7/2015	Task		Summary		External Milestone		Inactive Summary		Manual Summary Rollup		Finish-only	
	Split		Project Summary		Inactive Task		Manual Task		Manual Summary		Deadline	
	Milestone		External Tasks		Inactive Milestone		Duration-only		Start-only		Progress	

Page 7